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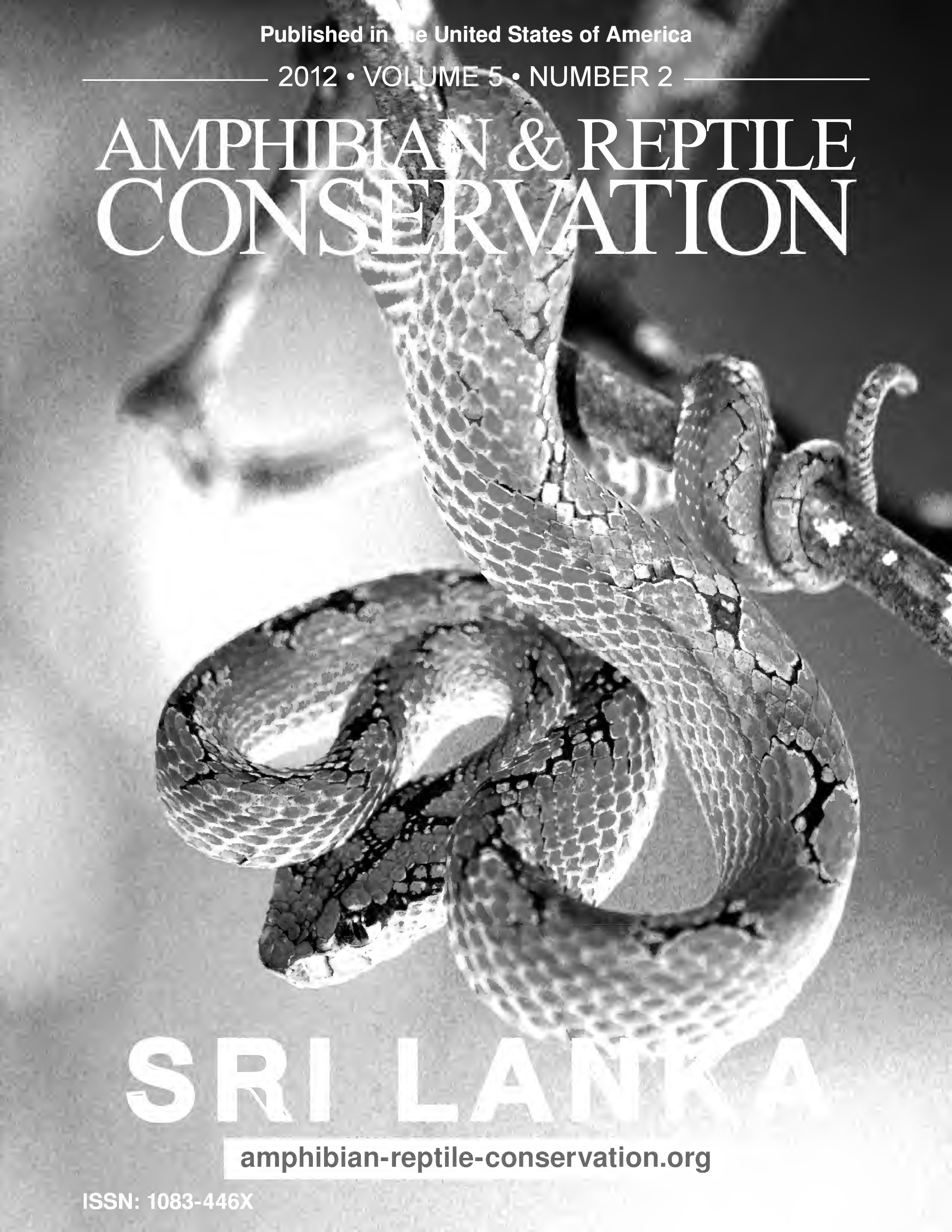

SRI LANKA

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Cover:

Green Pit-viper *Trimeresurus trigonocephalus* captured in Lakegala, Dumbara Hills, Knuckles World Heritage site, Sri Lanka. The sole representative of the genus *Trimeresurus* on the island of Sri Lanka; an endemic species. Nocturnal, sluggish and arboreal this snake is found in forested areas and occasionally in well-wooded home gardens and plantations such as tea, coffee, cardamom, cocoa, and clove nutmeg. More commonly distributed in the wet zone of the country but also found in the dry zone as well. Commonly found on low bushes and descending to the ground to search for prey at night. Generally found close to streams. *Photo Imesh Numan Bandara.*

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The herpetofauna of a small and unprotected patch of tropical rainforest in Morningside, Sri Lanka

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***Abstract.*—Morningside is an exceptional area in Sri Lanka with highly endemic herpetofauna. However, this relictual forest area lies inside a tea plantation and is mostly lacking conservation protection. Species inventories of remaining rainforest patches are currently incomplete, and information about the behavior and ecology of the herpetofauna of Morningside is poorly known. In our survey, we identified 13 amphibian species and recorded an additional two species that could not be identified with existing keys. We determined 11 reptile species from this patch of forest, and another unidentified *Cnemaspis* gecko was recorded. We did not assess the herpetofauna outside of this forest patch. Some species are described for the first time in Morningside, suggesting a wider distribution in Sri Lanka. We also document a call from a male *Pseudophilautus cavirostris* for the first time. Perspectives for future surveys are given.**

Key words. Survey, Morningside, Sri Lanka, herpetofauna, conservation, *Pseudophilautus cavirostris*

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Introduction

Sri Lanka is a small (65,610 km^2) island south of India. The island lies between latitudes 5°55' and 9°51' N and longitudes 79°41' and 81°54' E. Sri Lanka is divided into four different climatic zones (Domroes and Roth 1998): dry, wet, transitional, and semiarid. The dry zone is situated in the eastern and northern parts of the island, covering 60% of the total land area. Annual rainfall is between 1250 and 1900 mm, and the mean annual temperature ranges from 27° to 30° C. Floristically, the dry zone is characterized by monsoon forests and thorn scrublands. The wet zone encompasses southwestern Sri Lanka, covering 23% of the total land area and receiving an annual rainfall of 2500-5000 mm. The natural vegetation consists of evergreen, semi-evergreen, and rain forest. Between these two zones lies an intermediate transitional zone, with annual rainfall between 1900 and 2500 mm. The two semiarid zones (in the southeast and northwest) receive less than 1250 mm of rainfall annually. Within these zones, climate can also vary along elevational gradients. In mountainous regions, the temperature is lower and can approach freezing at times. This high elevation climate has been recognized previously from both the Central Mountains and the Knuckles Mountains, and more recently from the Rakwana Hills. All three of these mountainous regions have a different climate from the surrounding area, as expected (Werner 2001). The Morningside area lies in the Rakwana Hills.

In our attempt to understand the biodiversity of Sri Lanka, scientists from the Wildlife Heritage Trust (WHT) have made great progress in naming many new species and significantly expanding our knowledge of the region. However, there are likely still undescribed amphibians and reptiles in Sri Lanka (Anslem de Silva, pers. comm., Krvavac, pers. comm). Due to the high levels of endemism found in Morningside, scientists and conservation organizations like Conservation International have identified it as a region of high conservation priority. Located in the eastern part of the Sinharaja forest, Morningside has also been declared a Man and Biosphere Reserve (MAB Reserve) under the UNESCO World Heritage Convention. Sinharaja is the largest remaining tropical rainforest in Sri Lanka, but most unprotected parts of the forest in Morningside are logged. Today, only a few forest fragments remain.

Methodology

To survey Morningside for reptiles and amphibians, fieldwork was conducted for three days and nights in a small patch of remaining forest near the town of Suriyakanda in July 2010. This patch of forest lies inside a tea plantation and lacks any conservation protection, and it is possible that it will be cleared for tea plants in the near future. The coordinates of our survey starting point were identified

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with a handheld GPS (Garmin eTrex) as 6° 27' 17" N and 80° 37' 9" E at an elevation of 975 m asl (above sea level). We could not ascertain the size of the forest patch using the available resources. The forest lacks large trees (above 10 m) and the canopy is not completely closed. In this open canopy, sufficient light reached the ground and bushes were able to grow; it was often possible to see the sky through holes in the canopy. No attempts were made to identify vegetation. No rain was recorded during the study period, but strong winds prevailed during most of the sampling time. The surveys were conducted by walking along trails and a stream that flows through the forest, as well as by searching in and around ponds. The ponds had a depth of less than 60 cm and were considered to be temporary. Dead logs and rocks were overturned and leaf litter was checked for reptiles and amphibians. These surveys were done during daytime and at night between 8 p.m. and midnight.

Results

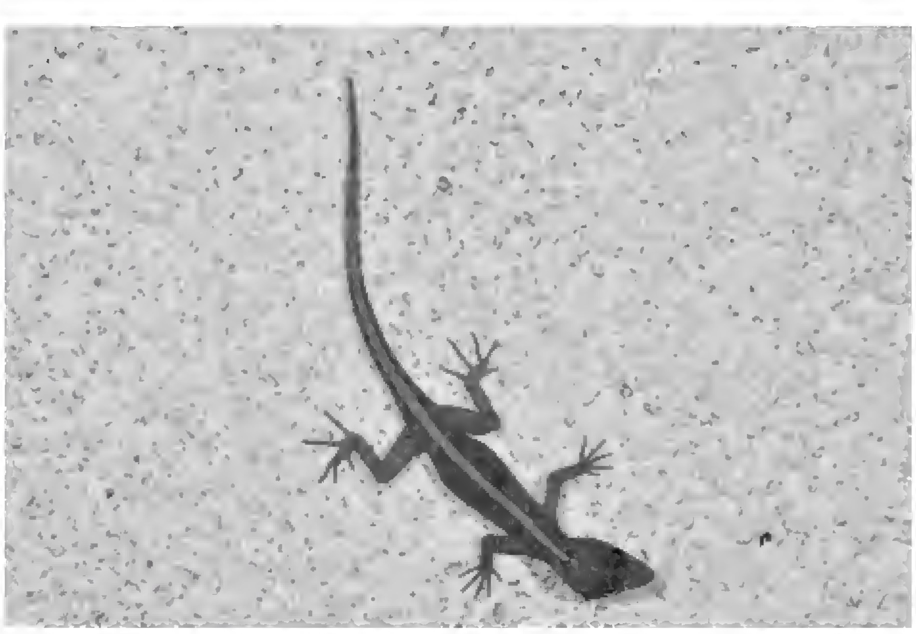
During the field trips, we found 15 species of amphibians, although two of these were unidentifiable using current taxonomy keys (not listed below). A total of 11 species of reptiles were identified, plus one unidentified gecko. All identified species are listed in Table 1.

Reptiles

Gekkonidae

Cnemaspis sp.

The genus *Cnemaspis* consists of day-active geckos. The species are more or less brownish to grayish in coloration. We found all specimens inside or around a small house nearby the forest. The geckos are common around the house, and they lay eggs in small holes in the doorframe. We could not find evidence for communal egg laying. This behavior is described for another member of the genus *Cnemaspis*, and we found a communal laying site of *Cnemaspis* at Morningside Estate, only a few kilometers away from this forest patch. Species identification of these specimens was not possible, as this genus must be reviewed for the whole of Sri Lanka, and in particular for Morningside. Several new species have been discovered, but remain undescribed (Anslem de Silva, pers. comm.).



Cnemaspis sp.

Cnemaspis sp.

Cyrtodactylus subsolanus

This gecko formerly belonged to the species *C. fraenatus* and was identified as a distinct species in by Batuwita and Bahir (2005). We found an adult specimen with total length 20 cm inside the house foraging for insects at night and a single young specimen in a bush during a trip in the late evening. The day gecko *C. subsolanus* is restricted to Morningside.

Cyrtodactylus subsolanus.

Tropical rainforest survey area in Morningside, Sri Lanka.

Table 1. Checklist of amphibians and reptiles found during the survey

Amphibians

Bufonidae

Adenomus kelaartii (Günther, 1858) endangered*

Dicroglossidae

Fejervarya kirtisinghei (Manamendra-Arachchi and Gabadage, 1996) least concern*

Microhylidae

Ramanella obscura (Günther, 1864) near threatened*

Ranidae

Hylarana temporalis (Günther, 1864) near threatened

Rhacophoridae

Pseudophilautus cavirostris (Günther, 1869) endangered*
Pseudophilautus fergusonianus (Ahl, 1927) least concern*
Pseudophilautus folicola (Manamendra-Arachchi and Pethiya goda 2005) endangered*
Pseudophilautus procax (Manamendra-Arachchi and Pethiya goda 2005) critically endangered*
Pseudophilautus reticulatus (Günther, 1869) endangered*
Pseudophilautus singu (Meegaskumbura, Manamendra-Arach chi and Pethiyagoda 2009) not evaluated*
Pseudophilautus stictomerus (Günther, 1876) near threatened*
Polypedates cruciger Blyth, 1852 least concern*
Polypedates fastigo Manamendra-Arachchi and Pethiyagoda 2001 critcally endangered*

Reptiles

Agamidae

Calotes calotes (Linnaeus, 1758) near threatened
Calotes liolepis Boulenger, 1885 vulnerable*
Lyriocephalus scutatus (Linnaeus, 1758) near threatened*
Otocryptis wiegmanni Wagler, 1830 near threatened*

Gekkonidae

Cnemaspis spec.
Cyrtodactylus subsolanus Batuwita and Bahir, 2005 not evaluated*
Geckoella triedrus (Günther, 1864) near threatened*

Scincidae

Lankascincus taprobanensis (Kelaart, 1854) near threatened*

Colubridae

Ahaetulla nasuta (Bonnaterre, 1790)
Dendrelaphis pictus (Gmelin, 1789)

Viperidae

Hypnale hypnale (Laurenti, 1768)*
Trimeresurus trigonocephalus (Latreille, 1801) vulnerable*

*Asterisk stands for endemic to Sri Lanka

Geckoella triedrus

This small gecko is a typical inhabitant of forests in the wet zone, but it is recorded from some parts of the dry zone as well. Das and De Silva (2005) restricted the elevational distribution to 700 m asl. However, we found our only specimen active at night at an elevation of 975 m asl. *Geckoella triedrus* is a small brown to black colored gecko with tiny whitish dots on the dorsum. This gecko is a member of the leaf litter herpetofauna living on the ground, and it is difficult to find.

Geckoella triedrus.

Agamidae

Calotes calotes

Calotes calotes is a widespread arboreal agamid found all over Sri Lanka up to 1500 m asl. The distribution ranges north into India. This agamid lizard is a typical anthropophilic species and is often found in gardens. We found a male *C. calotes* sleeping in the late evening at the forest border.

Calotes calotes.

Calotes liolepis

This agamid lizard is generally restricted to the wet zone, with a few exceptions in the intermediate and dry zone. In these drier areas, it is found on small hills with a slightly higher rainfall than the surrounding area. It is distributed in forests and plantations up to 1000 m asl. Our detection of *C. liolepis* in Morningside represents the highest regions in the distribution. *Calotes liolepis* is endemic to the region. This agamid species is difficult to find because it climbs the stems of trees and then curls around the stem, avoiding detection. All three specimens (one female and two males) that we found sat on a stem at heights between 4 and 6 m. One of the males had two bluish stripes laterally and an orange throat. The female was grayish colored. Somaweera found a specimen with red stripes (Manthey 2008). One of the authors (M.B.) found *C. desilvai* on an earlier trip in this forest patch. *Calotes desilvai* looks quite similar to *C. liolepis* and is restricted to a small part of the Morningside area (Bahir and Maduwage 2005). This is one of the few places where both species live in sympatry. However, we did not detect any *C. desilvai* on this trip.

Calotes liolepis.

Otocryptis wiegmanni

The kangaroo lizard is very common in the forests of Morningside. We found adults and young specimens frequently. This agamid is distributed throughout the wet zone and some parts of the intermediate zone as well. Only one species of the genus was described for Sri Lanka until Bahir and Silva (2005) described a new species

(*O. nigristigma*). *Otocryptis nigristigma* is restricted to the dry and intermediate zones. Male *O. wiegmanni* have a black patch on the dewlap, and by this they can be distinguished from *O. nigristigma*. *Otocryptis wiegmanni* is able to run bipedally when fleeing. *Otocryptis wiegmanni* can be found active during daytime or sleeping in the darkness on branches of trees and bushes.

Otocryptis wiegmanni male specimen.

Otocryptis wiegmanni sleeping.

Lyriocephalus scutatus

Lyriocephalus scutatus is restricted to the wet zone and few places of the intermediate zone below 1600 m asl, where it inhabits forests and home gardens. It is a slow-moving species and is mostly arboreal. Most specimens are light green or yellowish in coloration, although females are sometimes grayish or brownish. Young specimens are brownish and live on or near the ground in bushes or small trees. A unique defensive posture of this species is the display of the deep red color of the mouth. *Lyriocephalus scutatus* can easily be found in the darkness when they sleep and hang on tree stems. In the light of a torch, one can see them easily by the light coloration of the body. We found *L. scutatus* often, from very young to adult male specimens during both daytime and at night.

Lyriocephalus scutatus young specimen.

Scincidae

Lankascincus taprobanensis

Lankascincus are ground living species found in leaf litter. It is difficult to photograph these skinks because they quickly hide under leaf litter upon detection. *Lankascincus taprobanensis* is a mountainous species, distributed from 1000 m to 2300 m asl. We found this skink at their lowest distribution level in Morningside. The skinks are active during daytime and can be easily photographed at night.

Lankascincus taprobanensis.

Colubridae

Ahaetulla nasuta

Only one specimen was found in tree branches at the border of the forest at night. *Ahaetulla nasuta* is widely distributed across Sri Lanka and mainland Asia. This snake is often found in gardens in every climatic zone. There are no color varieties of *A. nasuta* in Sri Lanka. This opistoglyph snake is green-colored and becomes mottled when disturbed.

Dendrelaphis tristis

This slender and long snake has nearly the same distribution as *A. nasuta*, and we found one specimen nearly at the same place as the *A. nasuta* specimen. *Dendrelaphis tristis* is a common snake, more typically found in the lower parts of Sri Lanka. Das and De Silva (2005) gave a distribution range up to 750 m asl. We found this species 200 m higher in Morningside. The snake was hiding in bushes at night.

Viperidae

Hypnale zara

This venomous snake is endemic to Sri Lanka. It is a small brownish snake found in mountain and submontane forests living in leaf litter, where it can easily be overlooked. We found a specimen hiding around a pond at night.

Hypnale zara.

Trimeresurus trigonocephalus

Trimeresurus trigonocephalus is an arboreal snake with greenish ground color and often variegated black patterns. This species is distributed throughout Sri Lanka below 1075 m asl. We found one specimen hanging on branches next to a pond in the dark. It is a very docile species; the snake did not try to bite, but it did try to escape.

Trimeresurus trigonocephalus.

Trimeresurus trigonocephalus.

Amphibians

Bufonidae

Adenomus kelaartii

Adenomus kelaartii is a small slender toad found near streams, which is where we found our only specimen during the survey. It is a ground-dwelling species, but it can sometimes be found climbing on trees. *Adenomus kelaartii* is restricted to the wet zone and mountainous areas of Sri Lanka. There are no descriptions of eggs or tadpoles in nature, but there is a description of tadpoles from captive bred specimens (Haas et al. 1997; Haas 1999). We found one specimen together with *Hylarana temporalis*.

Adenomus kelaartii.

Dicroglossidae

Fejervarya kirtisinghei

This ranid like species is widely distributed in the lowland areas of Sri Lanka in the wet and the dry zone. In the past, *F. kirtisinghei* has been confused with *F. greeni*. The latter is restricted to the higher elevations of Sri Lanka. We found *F. kirtisinghei* near ponds together with *Hylarana temporalis* and *Ramanella obscura*. We observed tadpoles with the typical black tag in the pond.

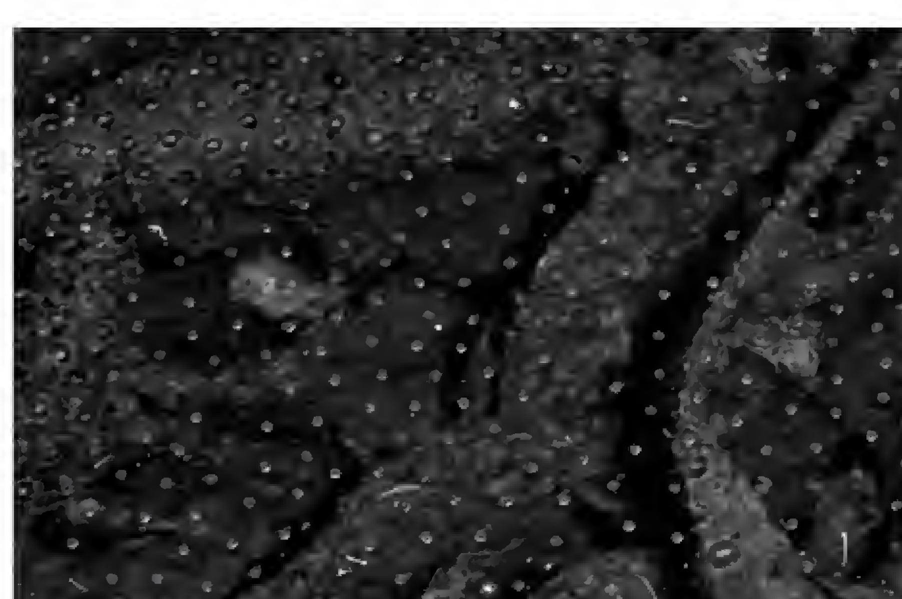
Fejervarya kirtisinghei.

Microhylidae

Ramanella obscura

Ramanella obscura is a small species (32 mm) living on the ground in leaf litter in shaded forests, but it sometimes climbs on trees and can be found in tree holes up to two meters high. It is distributed throughout the wet zone up to 1200 m asl. We found several specimens near or inside ponds. Egg clutches rest in a single layer on the water surface. We found *R. obscura* tadpoles together with tadpoles of *Fejervarya kirtisinghei* in the pond. Breeding of *R. obscura* in phytotelmata is described, but we only found egg clutches in ponds.

Ramanella obscura.



Ramanella obscura egg masses.

Ramanella obscura tadpoles in pond.

Ranidae

Hylarana temporalis

This is a typical species of the forest patch in Morningside. It is widely distributed in Sri Lanka's wet zone from the lowlands up to 1800 m asl. The frogs are mostly brownish-colored, with cross bars on the arms and legs. We found *H. temporalis* near the stream and near ponds, where the ground is wet or muddy. One frog had only one hind foot.

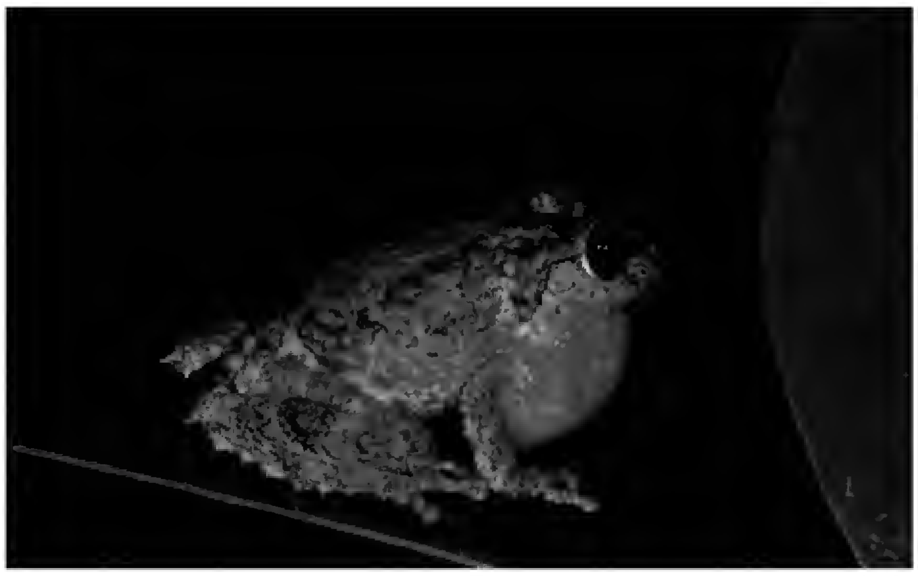
Hylarana temporalis.

Hylarana temporalis with missing foot.

Rhacophoridae

Pseudophilautus cavirostris

An arboreal species, *P. cavirostris* is perhaps found most often in canopies (Dutta and Manamendra-Arachchi 1996). This frog reaches 50 mm in length and has a tuberculated dorsum and fringes along the lower arms and tarsus. The coloration can be greenish or mottled with grey and brown. The frog is well camouflaged to look like lichens on a stem and is difficult and rare to find. Descriptions of eggs and mating behavior are not given elsewhere. We found a male specimen calling from leaves 1.5 m above ground around 11 p.m. Manamendra-Arachchi and Pethiyagoda (2005) suggested that males do not come down from the canopy because they could not find male specimens.



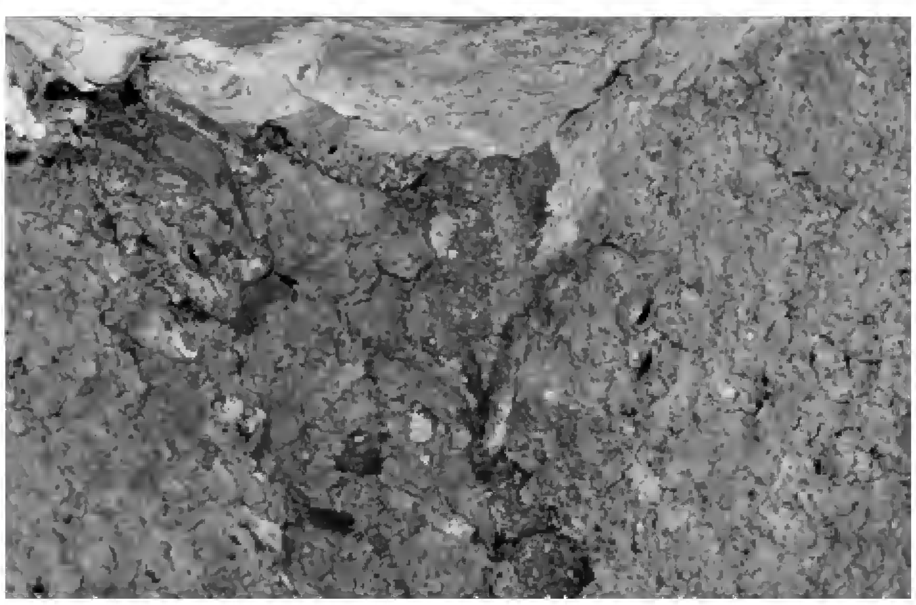
Pseudophilautus cavirostris calling.

Pseudophilautus cavirostris.

Pseudophilautus fergusonianus

This frog is found on trees and rocks in rainforests and rubber plantations in the hills of the wet zone between 300 and 700 m asl (Manamendra-Arachchi and Pethiyagoda 2005). We found several specimens, but only inside or at the house where we also found *Cnemaspis*. No specimens were observed in the forest. The coloration of *P. fergusonianus* gave an ideal camouflage on the house walls. This frog reaches 45 mm (females).

Pseudophilautus fergusonianus.



Pseudophilautus fergusonianus.

Pseudophilautus folicola

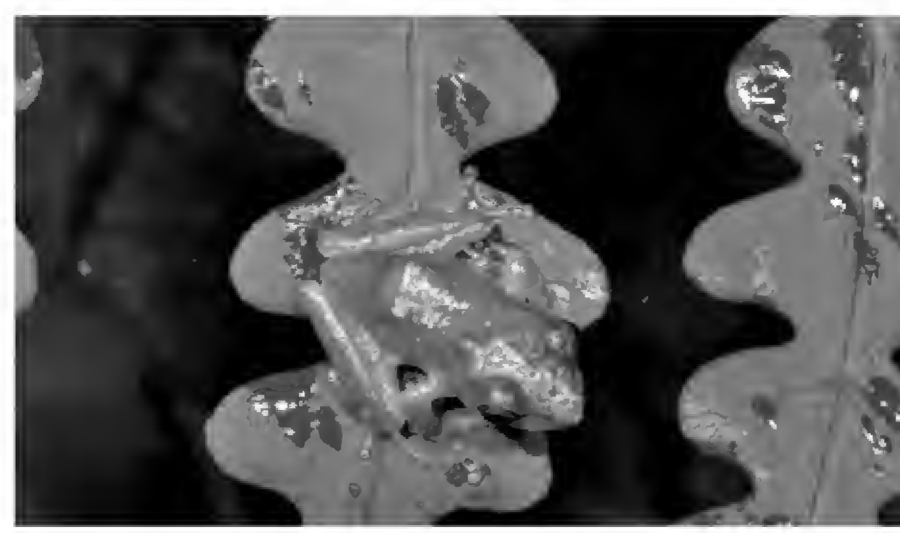
Pseudophilautus folicola was described as a lowland species from the wet zone (Manamendra-Arachchi and Pethiyagoda 2009). Our survey expands the distribution up to 975 m asl. It seems to be a common species, even found hiding in the daytime on garden plants.

Pseudophilautus folicola.

Pseudophilautus procax

Pseudophilautus procax is a tiny species (27 mm) found at night on leaves one to two meters above the ground. The coloration is light brown, sometimes a bit yellowish, with a yellowish to white infraorbital patch and red fingertips. This species is endemic to Morningside.

Pseudophilautus procax.



Pseudophilautus procax.

Pseudophilautus reticulatus

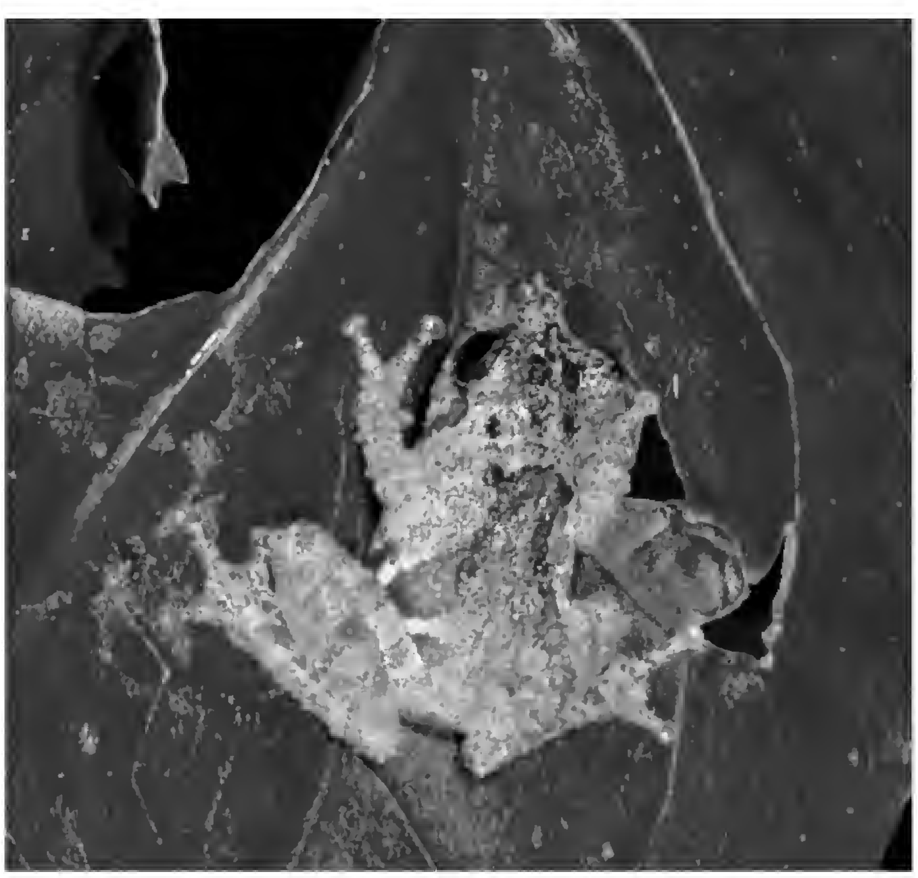
Pseudophilautus reticulatus is a larger species of the genus, with females reaching 61 mm. The scientific name for this species is derived from the markings down the lateral sides of the body and on the inner part of the femora. It is an arboreal species that comes down from canopies at night. In our estimation, this frog should be distributed in forests of the wet zone up to an elevation of 975 m asl. The true distribution of this species is unclear.

Pseudophilautus reticulatus: note markings down the lateral sides of the body and on the inner part of the femora.

Pseudophilautus reticulatus.

Pseudophilautus singu

We found specimens with grayish or light brownish ground coloration, which is in contrast to the original description of the species (Meegaskumbura, Manamendra-Arachchi, and Pethiyagoda 2009). It is a small species (males less than 20 mm), but females are not described and their size is unknown and undescribed in scientific papers. *Pseudophilautus singu* was found near ponds on leaves 1-2 m above the ground.



Pseudophilautus singu.

Pseudophilautus stictomerus

Pseudophilautus stictomerus is a small species (23 to 36 mm) from Sri Lanka's wet zone. Although it was assumed that this species is distributed to 700 m asl, we found this species at an elevation of 975 m asl. We found a small specimen, brownish-colored, with a fine white line from snout to vent and further along the hind legs and a yellow throat. The coloration of the throat could be an indicator for a male specimen.

Pseudophilautus stictomerus.

Polypedates cruciger

Polypedates cruciger is a large rhacophorid frog (male 60 mm and female 90 mm). It is a common species, found from the wet zone to the dry zone. It is a species that can be found in gardens and inside houses. Mating and breeding of this species is well known and documented (Herrmann 1993). We found two specimens at a pond inside the forest, sympatric with *Taruga fastigo*.

Polypedates cruciger.

Polypedates cruciger.

Taruga fastigo.

Taruga fastigo

Taruga fastigo is a beautiful tree frog and very similar to *P. longinasus*. *Taruga fastigo* is restricted to Morningside, and *P. longinasus* is a lowland species in forests of the wet zone. Unfortunately, there is no genetic verification that these are separate species. However, it is possible that both species live sympatrically in the Sinharaja forest. *Taruga fastigo* is a common species in this forest patch, and we found young and adult frogs at night on leaves and branches up to 2 m above ground. At the pond, we found a foam nest of *Taruga fastigo* containing a few unfertilized eggs. Further observations of *Taruga fastigo* are necessary, especially for breeding information, because this is a critically endangered species.

Polypedates fastigo.

Polypedates fastigo.

Taruga fastigo foam nest.

Discussion

During our brief survey, we found an interesting diversity of reptile and amphibian species, some of which were previously unknown from Morningside. This survey shows how much knowledge we are lacking about the distribution and ecology of reptiles and especially of the amphibians of Sri Lanka. Further investigations are necessary to answer these and future questions. The behavior and ecology of some of these species is currently not well known. One example of this lack of knowledge

is that we provide the first published record of a calling male *P. cavoristris*. This small patch of remaining tropical rainforest is ecologically valuable, an ideal place for a larger study of the ecology of such small forest patches and also for the ecology of these species of reptiles and amphibians. Also, little is known about the mating behavior and breeding of Sri Lankan amphibians (Karunarathna and Amarasinghe 2007). Future research is necessary and should be done in both nature and in captivity, as was previously conducted by Wildlife Heritage Trust at Agrapatana (Bahir et al. 2005).

This survey also highlights the need for more research at Morningside because some expected species were not detected on our trip. We could not find any specimens of the genus *Ceratophora* (*C. erdeleni* and *C. karu*), even though the Morningside Estate where they are known to occur is not far away from this forest patch. Both species are restricted to the Morningside region. We also found a few frog species only at Morningside Estate (*Pseudophilautus poppiae*, *P. sordidus*, and *P. decoris*), but not in the forest patch. It is possible that these frogs could be present in the forest patch as well, but escaped detection. One of the authors (M. B.) found *Microhyla karunaratnei* on a previous trip, but we did not find any specimens on the trip described here. We also found two species of *Pseudophilautus* that we could not accurately identify to the species level. These uncertainties, as well as its conservation priority, suggest that Morningside should be a target for future research on reptiles and amphibians.

Pseudophilautus unknown species.

Pseudophilautus unknown species.

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Predator-induced plasticity in tadpoles of *Polypedates cruciger* (Anura: Rhacophoridae)

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***Abstract.*—Aquatic tadpoles morphologically respond to presence of predators in various ways. Depending on the type of predator, tadpoles develop enhanced escape response abilities in acceleration, maneuverability, and speed, and these are correlated to suites of morphological characters, such as wider, longer, and robust tail related dimensions. Laying eggs away from water, such as in an arboreal foam nest from which partially developed tadpoles fall into water, could be an adaptation for predator avoidance of eggs and early tadpole stages. Since predation is of concern, even for these partially developed larvae, we sought to detect predator-induced morphological response (if any) of these forms compared to fully aquatic tadpoles. We exposed the tadpoles of foam-nesting *Polypedates cruciger* to a natural fish predator, *Belontia signata*. We show that at an early (Gosner stage 29-32) stage, tadpoles exposed to this predator develop a larger body size and increased tail-length related dimensions.**

Key words. Tadpole morphology, plasticity, foam nesting, *Polypedates cruciger*, predator-induced, morphological response, amphibian declines

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Introduction

It is well known that aquatic tadpole predators, such as some dragonfly larvae and fish, induce morphological changes in aquatic tadpoles (Anderson and Brown 2009; Buskirk 2002; Teplitsky et al. 2003). Morphological features of fully aquatic tadpoles, especially the ones that are important in swimming, such as tail dimensions, are known to change in response to predator-type, such as ambush predators and run-down predators. In the presence of ambush predators, tadpoles become acceleration/maneuver specialists, while in the presence of run-down predators, tadpoles become speed specialists. Morphological adaptations for such escape pathways include a broader tail (Lardner 1998; Laurila et al. 2006; Relyea 2002; Relyea 2003; Sosa et al. 2009; Teplitsky et al. 2003) or a longer tail, respectively (Higginson and Ruxton 2010; Moore et al. 2004; Relyea 2000). In some cases, the presence of predators causes early metamorphosis (Benard 2004; Higginson and Ruxton 2010; Relyea 2007; Werner 1986).

Morphological changes in response to predator presence occur in a diversity of amphibian taxa that are disparate both in phylogenetic and life-history traits. Frog species possessing different life-history traits show different anti-predator responses to different predators and competitors (Laurila et al. 2006; Relyea 2001a; Relyea 2001b; Relyea and Yurewicz 2002). For fully aquatic tadpoles, these morphological responses are now well known.

Laying eggs away from water in a foamy mass, in which tadpoles develop up to a pre-metamorphic stage before falling into water, is an alternative life history strategy, often known as foam nesting (Duellman and Trueb 1986). This strategy is considered to facilitate predator avoidance of eggs and early-stage tadpoles (Hodl 1992; Magnusson and Hero 1991), and to reduce the duration of the larval stage (through rapid development during the out-of-water phase).

The Hourglass treefrog (*Polypedates cruciger*), a Sri Lankan endemic, shows a derived reproductive strategy from aquatic egg deposition. These frogs make foamy nests overhanging water bodies, in which they lay their eggs. Tadpoles develop within the nest, up to Gosner stage 23 and then fall into water, where they undergo further development reaching metamorphosis. Adult *P. cruciger* are arboreal, but sometimes visit pools at night, apparently to rehydrate.

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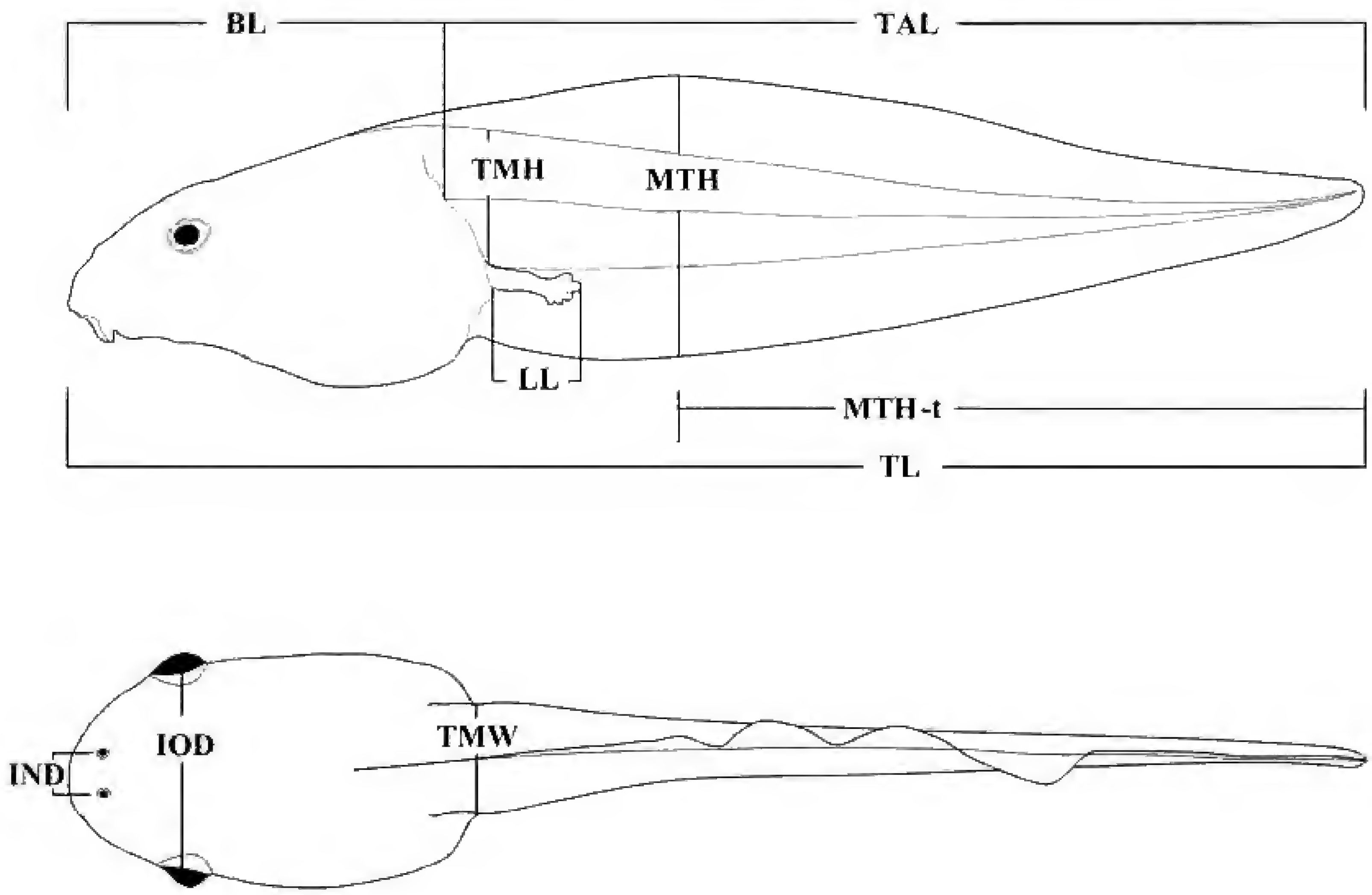

Figure 1. Outline of tadpole (lateral and dorsal views), depicting measurements that were used in this study: total length (TL), tail length (TAL), maximum tail height (MTH), maximum tail height to tip of tail (MTH-t), total muscle height (TMH), total muscle width (TMW), body length (BL), inter-orbital distance (IOD), internasal distance (IND), and limb length (LL).

Fish prey on such early-stage tadpoles that fall into water (this has been documented for other species, in which tadpoles of arboreal gel-encapsulated egg layers fall into water and are eaten by various aquatic predators; Magnusson and Hero 1991). Tadpoles of *P. cruciger* are preyed on by various fish species, including the Combtail, *Belontia signata* (Belontiidae), the Snakehead, *Channa orientalis* (Channidae), and nonnative and introduced Guppy, *Poecilia reticulata* (Poeciliidae; M. Meegaskumbura, pers. obs.). This study tests the developmental response of *P. cruciger* tadpoles to aquatic predation pressure.

Methods and materials

A single foam nest of *Polypedates cruciger* attached to a twig above a pond was observed in Peradeniya University Gardens, Sri Lanka (7°15'34.02"N, 80°35'49.71"E; 600 m asl). Tadpoles that emerged six days after the foam nest was first made (fertilization was observed) were reared in a glass aquarium for seven days, until the experiment began.

The experimental setup was as follows: eleven equally sized glass aquaria (size: 45 × 30 × 30 cm) each with 25 tadpoles was set up. Three of these were used as controls, and contained only tadpoles. Of the eight experimental aquaria, four contained tadpoles and fish, but visual contact between the tadpoles and fish was prevented by an opaque, water-permeable screen so that they shared the same water (chemicals produced by fish or tadpoles could thus be detected by any individual in the aquarium); these treatments were termed "closed" (they were established to provide tadpoles with an attenuated predator presence). The other four aquaria contained both tadpoles and fish, but allowing for visual (though not physical) contact between the predators and potential prey. They too, shared the same water, and were termed "open."

All other experimental conditions were kept identical for all tanks. The fish and tadpoles were fed a protein-rich aquarium-fish food. Daily partial water changes were made using water from an animal-free aquarium that had a UV-C sterilizer (to remove pathogenic organisms) and an aerating power filter (to aerate water and remove traces of chlorine and ammonia that could be present in tap water).

Samples were taken 12 days after the beginning of the experiment. They were anesthetized in MS222 and measured using a vernier caliper under a stereo microscope. Six tadpoles were sampled arbitrarily from each replicate. They were measured to ±0.01 mm using a digital caliper. The following measurements were taken: total length (TL), tail length (TAL), maximum tail height (MTH), maximum tail height to tip of tail (MTH-t), total muscle height (TMH), total muscle width (TMW), body length (BL), inter-orbital width (IOD), and internasal distance (IND; Fig. 1).

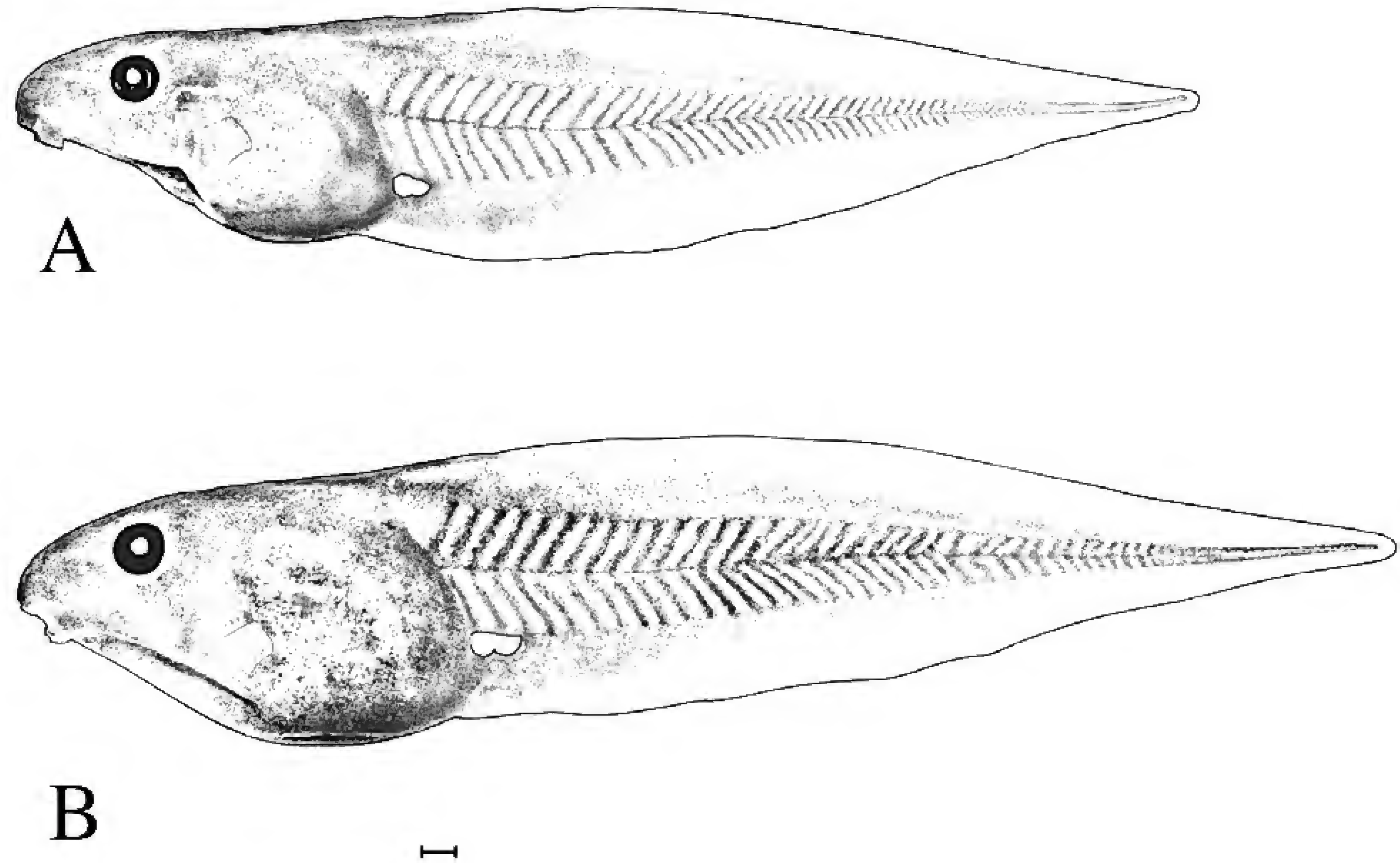

Figure 2. The morphology of early tadpole stages: A, control; B, "open." Scale bar 1 mm.

Coefficients of variation (CV scores) were determined and variables that had CV > 5%, and individuals that were outliers, were excluded from analyses. Prior to all analyses (except determination of CV scores) data were normalized through $\log_{10}$ transformation. The mean of each replicate was used in the subsequent analyses.

Systat version 11.00.01 for Windows XP was used for the statistical analysis. Principal Components Analysis (PCA) of means of character covariance matrix was used to reduce the dimensionality of morphological variables and to identify variables that may discriminate between the treatments. Different axis rotations were tested, and the one that yielded optimal interpretability of variation among variables is reported.

Discriminant Functions Analysis (DFA) was carried out to distinguish between the three experimental groups.

To visualize relationships between the variables of tadpole morphology, box plots depicting mean and standard error were made.

Results

Variables having CV scores > 5%, IND and LL, were excluded, leaving seven variables (TL, TAL, MTH, MTH-t, TMH, TMW, and BL) available for further analysis.

In the PC space of unrotated PC 1 and PC2 axes, the two treatments ("closed" and "open"), and the "con-

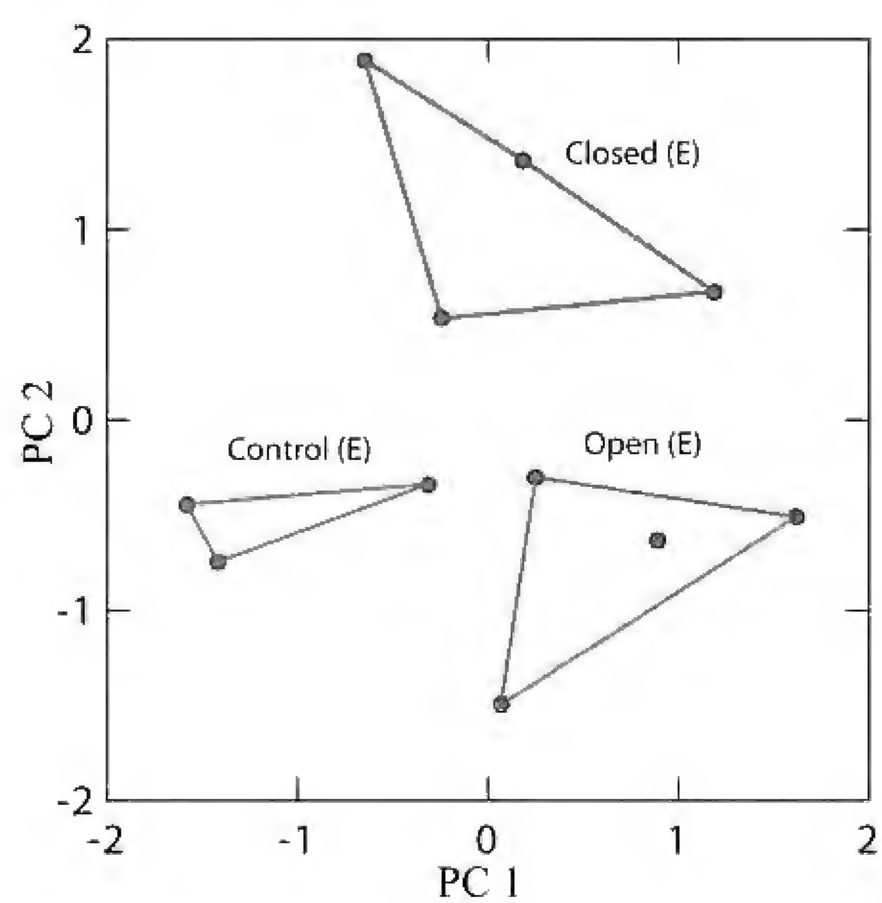

Figure 3. Principal components space of PC1 vs. PC2 (unregressed) of tadpole measurements in the two experimental conditions ("open" and "closed") and the controls of the early sampling regime. The PC1 axis, which explains 46% of the variance, is mostly represented by tail length, total length, and inter-orbital width. The PC2 axis, which explains 24% of the variance, mostly represents tail height-related variables.

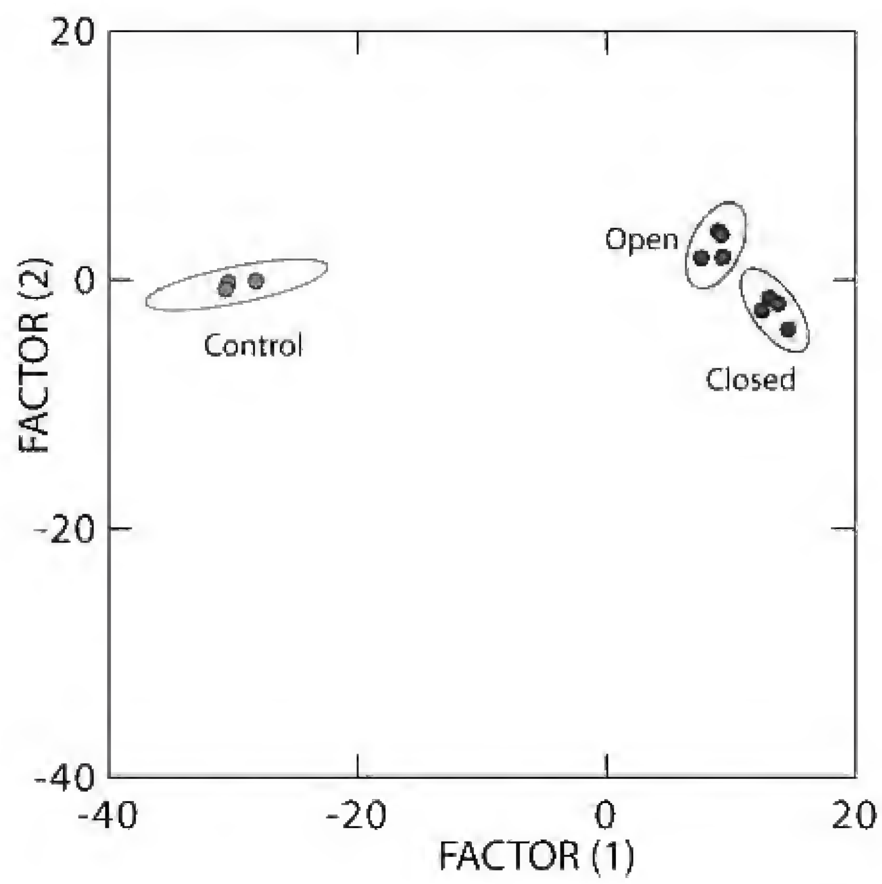

Figure 4. Canonical variables plot of discriminant function analysis (unregressed) of the two experimental conditions ("open" and "closed") and the control. Ninety-five percent confidence elipses of these three do not overlap with one another, and are centered on the centroid each group.

trol" tadpoles separate well (Figs. 3, 4). On the PC 1 axis, which explains 46% of the variance, several variables representative of tail and total lengths, and IOD load heavily (component loadings: TAL = 0.889, MTH-t = 0.871, IOD = 0.869, TL = 0.825; TMW = 0.667; Table 1). On this axis, "control" and "open" do not overlap, but "closed" overlaps with both the former cases and is placed in between these. Hence, presence of fish seems to increase total and tail-length related dimensions in tadpoles. On the PC 2 axis, which explains 24% of the variance, "closed" does not overlap with either "open" or "control." However, both "open" and "control" overlap with each other completely on this axis, which is mostly explained by tail height-related variables (component loadings TMH = 0.811, MTH = 0.624; Table 1). Considering unrotated PC 1 vs. PC 3, PC 1 vs. PC 4, PC 2 vs. PC 3, and PC 2 vs. PC 4 for these, the treatments and controls overlap with each other to various degrees on the PC 3 and PC 4 axes (not shown) but, as explained above, not on the PC 1 and PC 2 axes.

The Discriminant Functions Analysis shows that the 95% confidence ellipses do not overlap with each other (Fig. 4).

Some of the tail-length associated variables (means and standard errors) (TAL, MTH-t, TL, and TMW) show distinctions among the three groups; only the box plot of MTH-t is shown (Fig. 5).

Discussion

Because of predation, developmental anomalies, pathogens, and unfavorable environmental conditions, not all amphibian larvae develop to metamorphosis. Often entire egg clutches are destroyed even before tadpoles become free swimming.

Predation reduction of egg and early stage tadpoles has been suggested to have driven the evolution of egg deposition out of water for many forms (Doughty 2002). This hypothesis is plausible, but predator avoidance is still important even after early-stage tadpoles of foam-nesting species fall into water. Indeed, we have observed tadpoles of *P. cruciger* being preyed upon by various fish species. Once a falling tadpole is detected by predatory fish, it lurks under the nest waiting for more tadpoles to fall (M. Meegaskumbura, pers. obs.). In such a situation, there is clearly an advantage for tadpole's ability to evacuate the impact area as soon as possible. We have observed this: tadpoles of *P. cruciger*, upon impacting the surface of the water, quickly react by swimming away rapidly, in an apparently arbitrary direction, until

Table 1. Component loadings for axes 1-4 for the Principal Component Analysis, variance explained, and percentage of total variance explained for early sample treatments and controls (unregressed: "open," "closed," and "control").

	Component Loadings			
	1	**2**	**3**	**4**
TAL	0.889	-0.341	-0.160	0.241
MTHT	0.871	-0.188	-0.297	-0.232
IOD	0.869	0.332	0.007	-0.312
TL	0.825	-0.466	0.112	0.281
TMW	0.667	0.477	0.349	0.374
TMH	-0.102	0.811	-0.242	0.464
MTH	0.407	0.624	0.514	-0.370
BL	-0.188	-0.401	0.874	0.128
Variance Explained by Components	3.642	1.914	1.335	0.796
% of Total Variance Explained	45.530	23.929	16.686	9.955

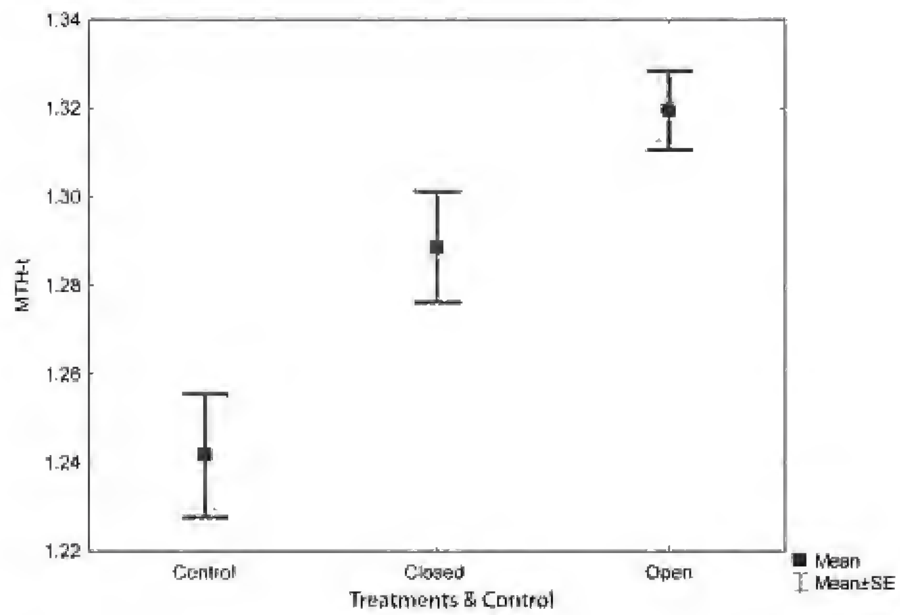

Figure 5. Boxplot depicting the means and standard errors of the two treatments ("open" and "closed") and the control.

they reach a safe submerged refuge. Furthermore, even though young tadpoles are attached by their cement glands to underwater substrates at this stage, they react quickly to any disturbance by fast and apparently random swimming (M. Meegaskumbura, pers. obs.). These observations are indications that effective swimming is an important survival attribute in tadpoles.

PCA and DFA results are complementary and show tadpoles of the "control" and "open groups" to be divergent in body morphology. It is known that a larger body confers reduced risk of predation (Buskirk and Schmidt 2000), as this enables animals to swim faster, or accelerate and maneuver better. The "open" body morphology of *P. cruciger* tadpoles matches the features of tadpoles from other unrelated taxa that respond to predation by achieving a fast-swimming body morphology e.g., longer tail, greater total length: Buskirk and Relyea (1998); Teplitsky et al. (2003).

Behavioral plasticity might be inexpensive due to absence of a need for new or altered structures to meet new challenges (Buskirk 2002). Though behavioral response of tadpoles to predators was not quantified in this study, we observed that tadpoles from "open" tanks reacted most swiftly to disturbances when compared to "closed" and "control" groups.

We have yet to study the effects of predator presence on early metamorphosis, something that several other authors have previously reported on (Gomez-Mestre et al. 2008; Lardner 1998; Vonesh and Warkentin 2006). If early metamorphosis occurs in tadpoles that develop in association with a predator, the resulting tadpoles may have a smaller body (Lardner 1998).

Although our data demonstrate that *P. cruciger* tadpoles exhibit predator-induced plasticity, they reveal little about the patterns of plasticity. For example, we do not know whether all tadpole stages show predator induced plasticity, or if the presence of predators induces early metamorphosis. Further experimentation is warranted.

Multiple layers of protection, initially through harboring of the vulnerable early developmental forms in a foam nest, and later, after partially developed tadpoles fall into water, in the accelerated development responses to aquatic predator presence, seem like adaptations to help survive in a predator high environment. If foam nesting evolved as a response to predator avoidance of early tadpole stages, it can be argued that there was a heavy predation cost for the aquatic larvae, at least historically. Then even the partially developed tadpoles would have to face some form of predation, from the very predators that would have eaten them as early-stage larvae, had the eggs been laid in water, even though at a reduced intensity. These adaptations could be a reason for the wide distribution of this species across several habitat types in the wet and the intermediate zone of Sri Lanka. It will be interesting to determine whether adaptations observed in *P. cruciger* are seen also in tadpoles of *Taruga*, its sister genus (Meegaskumbura et al. 2010).

Introduced predatory fishes may have various feeding mechanisms, which tadpoles living in these waters may not be adapted to. For instance, to avoid predation from an ambush predator, an accelerating or maneuvering tadpole body form may be needed. If this is not present, an introduced form may destroy whole populations of tadpoles.

Hence, when causes for decline of amphibians are considered in the context of to introductory predatory fishes or aquatic predators, study of tadpole morphological adaptability may be important to determine the actual mechanisms of decline.

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Morphology and ecology of *Microhyla rubra* (Anura: Microhylidae) tadpoles from Sri Lanka

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***Abstract.*—The life-history, ecology, external and buccal morphology of *Microhyla rubra* (Jerdon, 1854) tadpoles are described. Approximately 400 eggs, ready to hatch, were observed as a single mass and several of these were reared in laboratory. Tadpoles showed several characters that are not seen in most other microhylids: a whip-like tail-end flagellum, a dorsoterminal mouth, a transparent body, absence of flaps and existence of a median notch on upper lip, presence of papillae (or scallops) on lower lip, and a deep ventral tail fin (compared to the dorsal tail fin). *Microhyla rubra* tadpoles also have several features, so far not noted in other microhylids: six papillae (or scallops) on lower oral flap, a crescent-shaped spiracular opening, and an enlarged crest on ventral tail fin. For some characters, such as shape of the oral flaps, we show that there is considerable variation within and between Gosner stages. This species deposits its eggs as rafts in ephemeral pools where water chemistry (bound ammonia, salinity, conductivity, pH, sulphate ion concentration) and temperature are apparently favorable for rapid growth, reducing the risk of predation from fully aquatic predators. Since oxygen concentrations in these habitats are low and free ammonia concentrations are moderately high, occupying surface layers of pools would enable the eggs and tadpoles to overcome these impediments to growth and survival.**

Key words. Microhylinae, microhyline tadpoles, morphology, buccal, ecology, *Microhyla rubra*

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Introduction

The natural history and reproductive biology of microhylid frogs are poorly known (Wassersug 1980; Donnelly et al. 1990; Lehr et al. 2007). Although descriptions of tadpole characters useful in taxonomy have been described only for a few species, tadpole morphology varies considerably both inter- and intra-specifically (Donnelly et al. 1990). Hence, it is important to study tadpole morphology in greater detail, making inter-species comparisons more useful for phylogenetic and comparative-morphological analyses.

The Red narrow-mouthed frog, *Microhyla rubra*, is widely distributed in the lower elevation regions of Sri Lanka, peninsular India, and Bangladesh, rarely occurring above 500 m asl (Kirtisinghe 1957; Manamendra-Arachchi and Pethiyagoda 2006; IUCN 2004); it is found predominantly in drier parts of these countries. The species is often found under logs, piles of rubble, haystacks, and stones, where comparatively higher moisture levels exist. Small size, nocturnal habits, and cryptic nature of these frogs make them difficult to encounter in the field.

Nonetheless, *Microhyla rubra* is categorized as "Least Concern" by the IUCN, due to its wide distribution, tolerance of dry environmental conditions, and high population densities.

Despite their abundance, details of the life history of *Microhyla rubra*, especially tadpole characteristics and biology, are still poorly known. Several previous workers (Rao 1918; Parker 1928, 1934; Kirtisinghe 1957, 1958) have described the external morphology of the tadpoles, and Rao (1918) states that they are not transparent. Kirtisinghe, (1957) provided a brief description of the external morphology of the tadpole, including presence of a tail-end flagellum, dorso-terminal mouth, spiracular opening above a notched flap on underside of the belly, and the deep lower crest of the ventral tail fin. Kirtisinghe (1957) provides a drawing of oral flaps, but without a description. Internal buccal morphology is not discussed by any of these researchers.

Here we provide a more complete description of the external morphology of *Microhyla rubra* tadpoles and provide the first description of their buccal morphology. We particularly concentrate on the mouth location, spiracle location, shape of spiracular opening, tail morphology, and mouthparts, as these features are shown to vary considerably among and within microhylids (Donnelly et al. 1990) and are of potential importance in systematics.

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Figure 1. Open and shallow ephemeral pool lined by grass and shrubs, where floating eggs were sampled.

Methods and materials

Location (08°16’49.43” N, 80°28’49.96” E): Several eggs in late embryonic stages were collected (identity of species was not known at time of collection) from an ephemeral man-made pool near Nachchaduwa reservoir in Anuradhapura (Fig. 1). Tadpoles at Stage 24 (Gosner 1960) emerged from these eggs after two days. These tadpoles were raised in the laboratory, with partial daily water changes of dechlorinated water, and periodically sampled until metamorphosis. Tadpoles were fed on boiled egg yolk. Metamorphs were raised an additional month, and identified using taxonomic keys devised for adult frogs (Manamendra-Arachchi and Pethiyagoda 2006). Tadpoles were fixed in 10% buffered formalin for two days and preserved in a 1:1 mixture of 10% buffered formalin and 70% alcohol. Tadpoles are deposited in the collection of the Department of Zoology, University of Peradeniya, Sri Lanka (DZ).

Grillitsch et al. (1993) and McDiarmid and Altig (1999) were followed for external description of tadpoles. For internal oral anatomy, a combination of Khan (2000) and Wassersug (1976) was followed. The surgical method delineated by Wassersug (1976) was used and the following measurements were taken (Fig. 2): maximum height of body (bh), maximum width of body (bw), maximum diameter of eye (ed), maximum height of tail (ht), maximum height of lower tail fin (lf), internarial distance (nn), naro-pupilar distance (np), interpupilar distance (pp), rostro-narial distance (rn), distance from tip of snout to opening of spiracle (ss), distance from tip of snout to insertion of upper tail fin (su), snout-vent length (svl), total length (tl), maximum height of upper tail fin (uf), distance from vent to tip of tail (vt), tail muscle height (tmh), and tail muscle width (tmw). Morphology was observed using a Motic zoom-stereomicroscope (6-50 ×). Tadpoles were measured using digital calipers (measured to the nearest 0.01 mm).

Results

Description of tadpole

External morphology. The following description is based on five Stage 35 tadpoles of *Microhyla rubra* (DZ 1033-37) except where explicitly stated.

In dorsal view, body clearly differentiated into two parts, a longer and wider anterior region (R1) and a narrower posterior region (R2). Anterior region almost twice as long and wide as posterior region (Figs. 2 and 3). Eyes

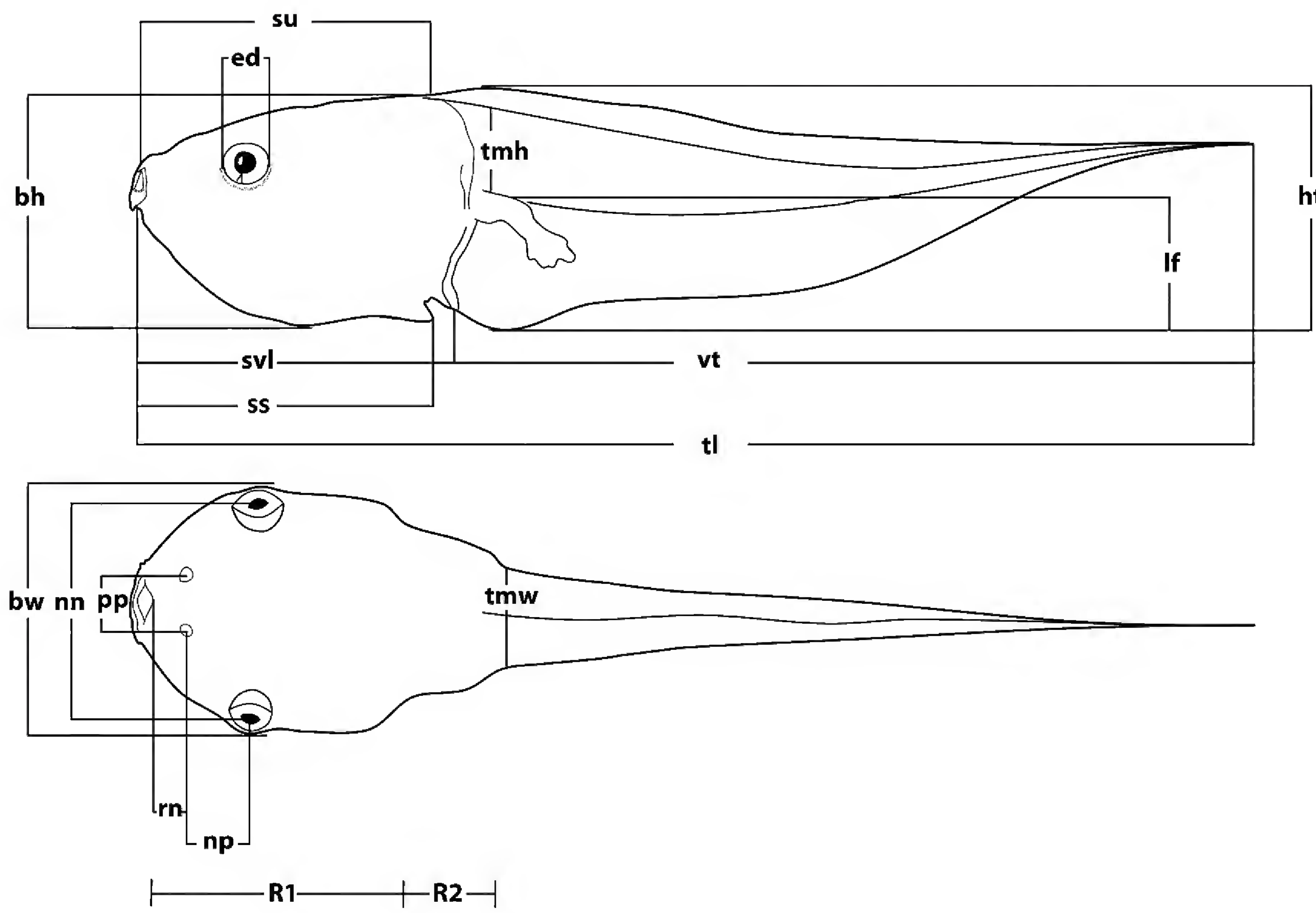

Figure 2. Outline of *Microhyla rubra* tadpoles showing the measurements that were taken.

small (ed/bw = 0.22) and snout rounded. Head and body posterior to eyes with sides parallel to each other, and conjunction of R1 and R2 forms an angle of 137-148°. Eyes directed slightly dorsolaterally, bulbous, and entire eye visible through epidermis due to dearth of pigmentation. Nares closed (nn/pp = 0.21), narial depressions visible, oval, unpigmented to slightly pigmented, located immediately anterior to two small concentrated patches of pigment, anterodorsolaterally directed, and closer to snout tip than to pupils. Nasolacrimal duct apparent. A lateral protruding ridge anterior to eye. Mouth narrow, superior, lower and upper-lips both visible. Tail long, tapering, with a whip-like flagellum (pointed tail tip; Fig. 4).

In profile, R1 wedge-shaped, pointed at snout, anterior-dorsal aspect straight, and anterior-ventral aspect slightly rounded. R2 ventrally rounded and dorsally slightly rounded. Gut contained in R2, overlaid with iridophores (Fig. 3E). A paired gas-filled cavities present dorsolateral to the gut (probably the developing lungs); horizontal dark bar located dorsal to gas-filled cavities. Spiracle mid-ventral, transparent, ends at posterior ventral part of body, dorsally attached to body wall, and ventrally free with a small posteriorly extending flap with medial notch near vent. Ventral tail fin begins at the dorsal attached end of the spiracular opening. Spiracular opening crescent-shaped with anterior portion of the ventral tail fin contained within the spiracle (Fig. 3C). Vent tube in lower tail fin, posterior to spiracle opening. Tail musculature weak, extending to end of tail tip (tail-muscle height/body height = 0.43; tail-muscle width/body width = 0.31), V-shaped myomeres apparent only in posterior two-thirds of tail (Fig. 3A). Dorsal tail fin deeper than ventral tail fin, both fins originate above and below the same vertical point on body. Fins reduced towards end, proximally a deep convex extension of ventral tail fin (lowest crest) distally, a smaller crest towards middle of tail (Fig. 5).

In ventral view, eyes barely visible, but silhouette of eye-ball apparent through unpigmented skin. Extended flap of lower lip visible. Coiled gut visible, positioned slightly to left of midline, overlaid with iridophores. Heart at boundary of R1 and R2.

Oral flaps: upper lip not fleshy (Fig. 3B), with a slight medial notch. Edge of lower lip slightly scalloped, with three projections on each lobe (Fig. 8).

Buccal morphology

Labial keratinized teeth were absent in all individuals examined.

Ventral buccal region. Prelingual arena U-shaped, length greater than width, curved portion of U directed anteriorly toward oral aperture. A pair of dorsally-direct-

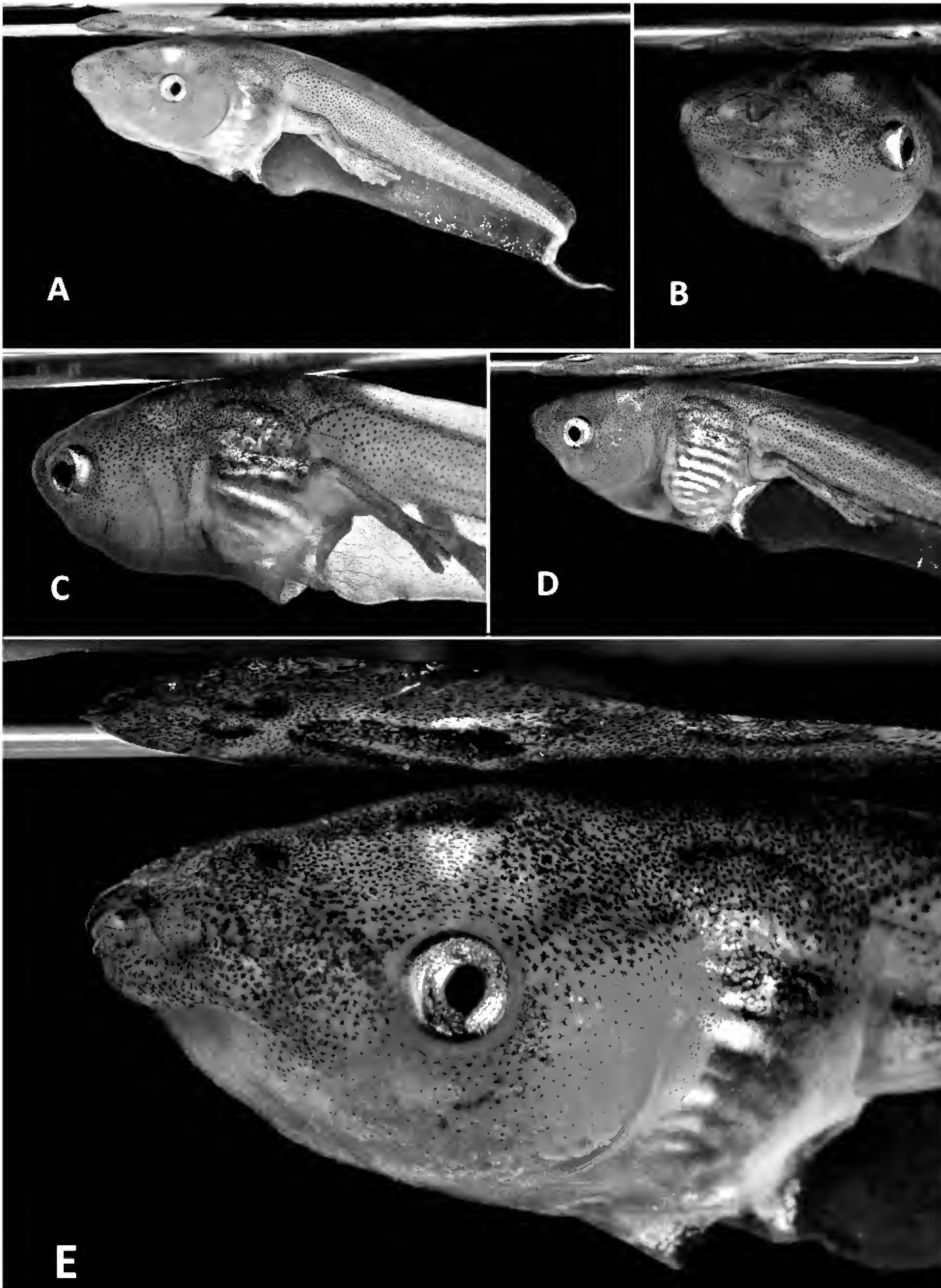

Figure 3. *Microhyla rubra* tadpole (Stage 38) in life showing: (A) the long tail with a distinct flagellum, (B) position of mouth, (C) shape of the spiracle and position of the vent tube in tail, (D) Shape of the convex curvature in ventral fin, and (E) close up of the head and body showing the nasolacrimal duct, distribution of pigmentation, mouth position, and groove on non-fleshy upper lip.

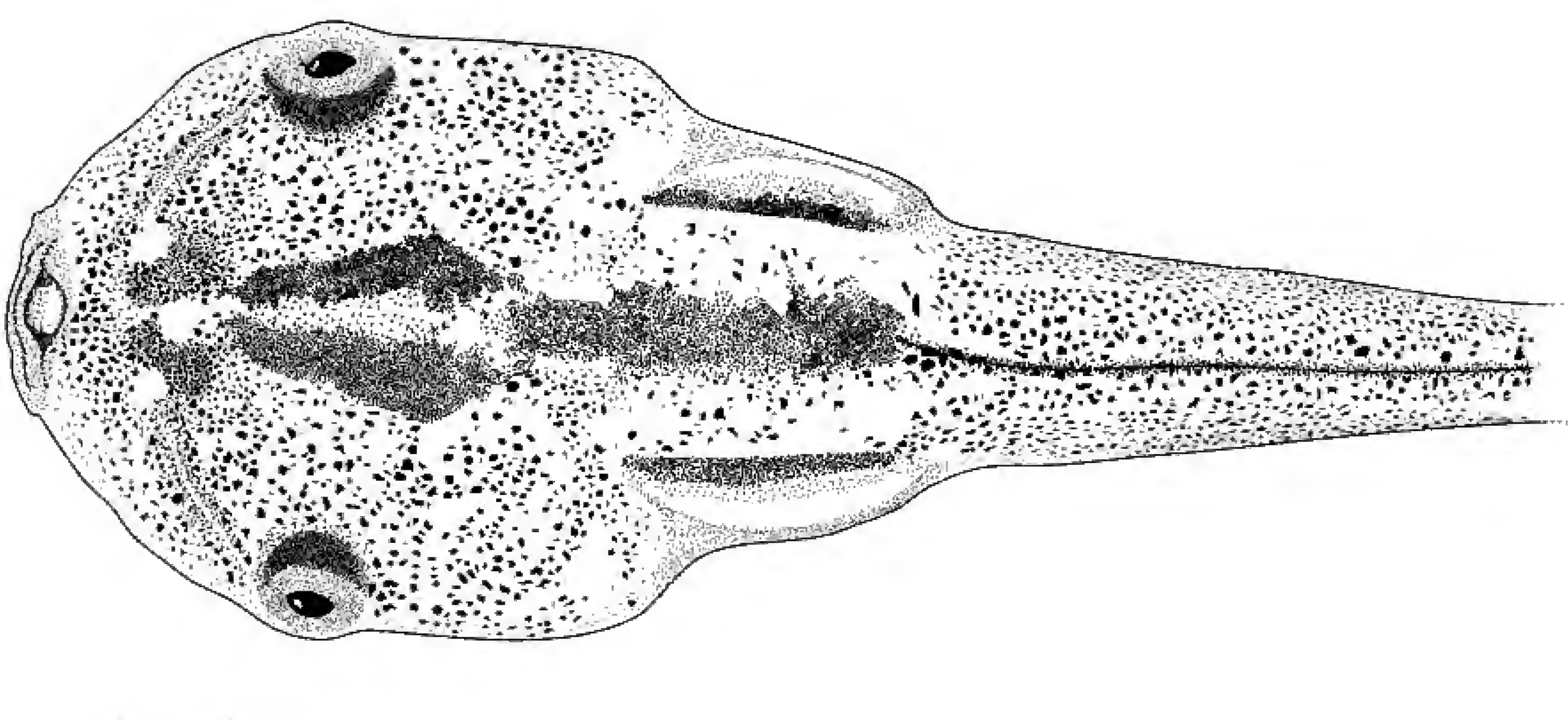

Figure 4. Dorsal aspect of the body and part of the tail of a *Microhyla rubra* tadpole (Stage 35). Scale bar, 1 mm.

ed lateral infralabial papillae of equal size line mouth opening. Fleshy fold on the lateral walls of mouth opening. A fleshy fold on mouth floor posterior to infralabial papillae, directed towards buccal cavity. A pair of lateral buccal pockets in anterior region of buccal floor. A single pair of small papillae on anterior wall of buccal cavity, on either side of mouth aperture, not attached to tongue. Conical, non-papillated tongue anlage, broader anteriorly, without pigment, narrower and free posteriorly, with pigment. Buccal floor arena (BFA) triangular, laterally elevated, medially depressed, forming a narrow passage at the anterior portion of BFA, posterior end of buccal floor much broader than anterior end. Two small and blunt, two large, and one medium-sized symmetrical pairs of conical BFA papillae. Small papillae (length = 0.07 mm) anterior to all others. Medium papillae (length = 0.16-0.19 mm) close to glottis. Large papillae (length = 0.27-0.34 mm) further from glottis, posterior to medium papillae. Single conical large medial preglottal papilla. Buccal pockets long and narrow, sickle-shaped, and blunt at the blind end. A pair of symmetrical, small blunt proximal prepocket papillae. Pairs of one large conical, three medium conical, four small blunt postpocket papillae. A large conical medially curved distal and sinistral prepocket papilla. A large and medium conical, medially curved, distal dextral prepocket papilla. Trachaea club-shaped, protruding from base of velum, extending to base of BFA, ending in elevated lips. Broad ventral velum without strong spicular support, free margin of velum smooth, covered by secretory pits, and containing a single broad projection above third filter plate (Fig. 6).

Dorsal buccal region. Choanae blind ended. Prenarial arena a posteriorly-directed V-shaped depression. Prenarial papilla, single, medial, small, blunt, placed anterior to narial papilla. Narial papillae hang from narial depression, slightly twisted, long, flat, robust, with three projections towards the anteriorly-directed tip; the middle projection longest. Postnarial ridge slightly serrated. Buccal roof arena (BRA) triangular, broad anteriorly, and lined by postero-lateral BRA border with papillae. Close

Table 1. Means and standard deviations of 12 tadpole body measurements of *M. rubra* at different Gosner stages (26, 31, 33, and 35).

Characteristics	Stage 26	Stage 31	Stage 33	Stage 35
	n = 2	*n* = 2	*n* = 2	*n* = 6
Body height (bh)	2.45 ± 0.02	3.63 ± 0.01	4.60 ± 0.15	5.54 ± 0.67
Body width (bw)	2.83 ± 0.37	4.47 ± 0.06	5.79 ± 0.21	6.41 ± 0.66
Maximum tail height (th)	2.98 ± 0.32	4.49 ± 0.32	5.24 ± 0.04	6.26 ± 1.07
Inter narial distance (nn)	0.64 ± 0.01	0.89 ± 0.01	1.07 ± 0.02	1.23 ± 0.12
Inter pupular distance (pp)	2.68 ± 0.37	4.20 ± 0.09	5.50 ± 0.22	5.94 ± 0.83
Snout-vent length (svl)	4.24 ± 0.09	5.85 ± 0.30	7.40 ± 0.34	8.67 ± 1.22
Total length (tl)	14.48 ± 1.65	20.59 ± 2.47	26.23 ± 0.55	29.00 ± 3.11
Vent to tail tip length (vt)	10.24 ± 1.75	14.74 ± 2.18	18.83 ± 0.21	20.39 ± 2.01
Tail muscle height (tmh)	1.07 ± 0.13	1.93 ± 0.30	2.23 ± 0.01	2.35 ± 0.24
Tail muscle width (tmw)	0.66 ± 0.01	1.33 ± 0.09	1.69 ± 0.24	1.98 ± 0.29

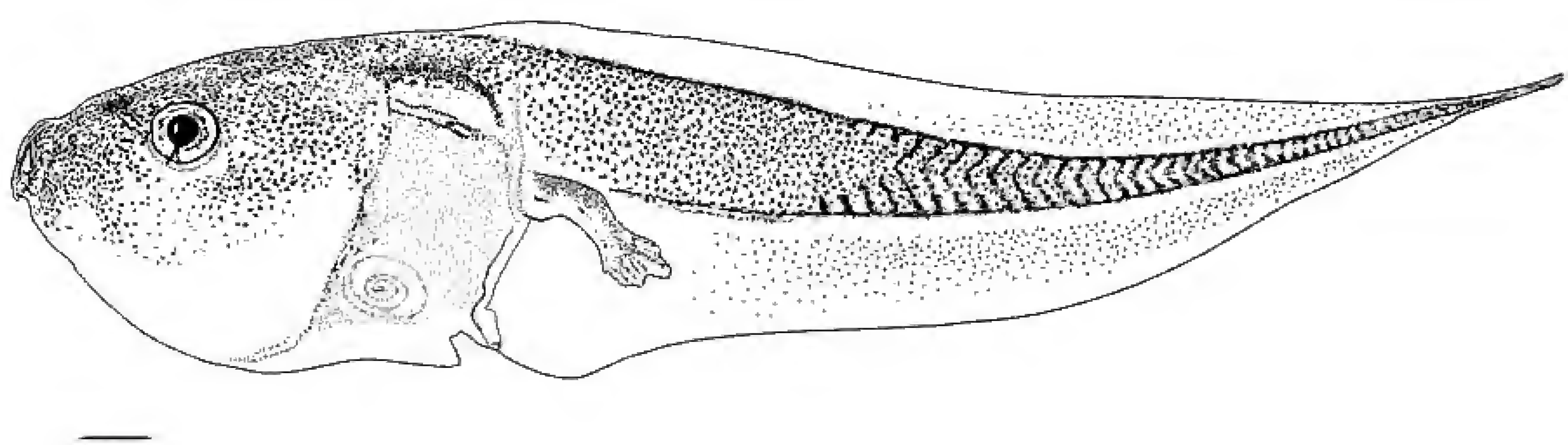

Figure 5. Profile of the whole body of the *Microhyla rubra* tadpole (Stage 35). Scale bar, 1 mm.

to BRA apex, one pair long (length = 0.44-0.47 mm) and pointed; one pair medium (length = 0.14-0.19 mm) and pointed; BRA papillae, lateral to apex; BRA border with a few small (length = 0.04-0.06 mm) BRA papillae. Broad roof glandular area anterior to dorsal velum and dorsal velum gradually thins medially (Fig 7).

Ventral pharynx region. Branchial baskets triangular, half of the filter cavities anterior to the velum, and all three filter plates distinct. A distinctly ridged oval torus present in each filter cavity and subvelar surface with many secretory ridges (Fig. 6).

Color in life. Body transparent and light yellowish grey. In profile, dorsum densely pigmented compared to venter, pink region present between eyes and coiled gut. Iris silver, with dark inverted V-shape at ventral edge. R2 studded with silver iridopores and dark-brown pigment cells (Fig. 3E). Tail fins lightly pigmented in dark brown.

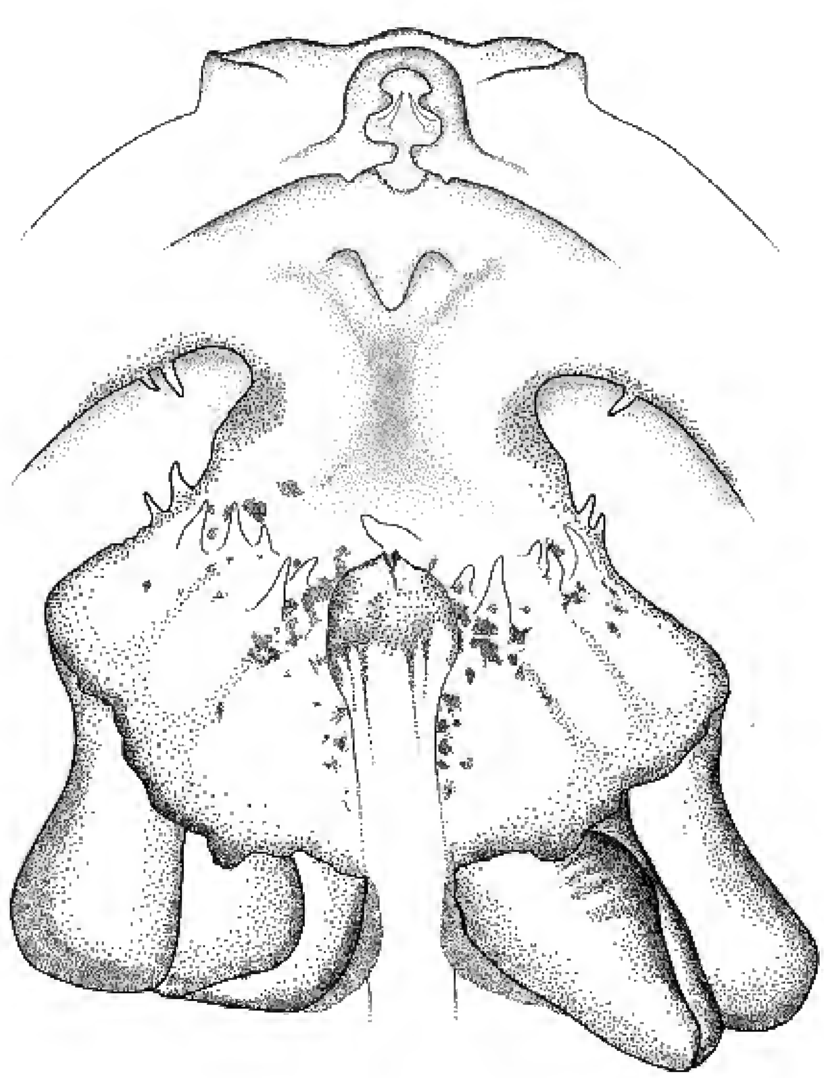

Figure 6. Ventral buccal morphology of the *Microhyla rubra* tadpole (Stage 35). Scale bar, 1 mm.

Tail musculature equally pigmented throughout, size of pigment patches reducing posteriorly (Fig. 3A, B, C, and D). Upper margin of the hind limb and toes pigmented (Fig. 3A, C, and D). In dorsal view, densely pigmented areas located near nasal openings, between nasal opening and point of origin of upper tail fin, along the base of the upper tail fin and in the gas-filled cavities. Posterior to nasal markings a red band extends to margin of R1 and R2. Eyeballs apparent and black in color.

Color (preserved). Body semi-transparent to brownish-white, tail lighter color than the body. Pigments on body star-shaped, giving the appearance of powder coating. Higher densities of pigments occur dorsally than ventrally. A median symmetrical dorsal band of dark brown to black melanophores covers the brain region and extend to near the base of eyes and nasal pits. Dark brown to black pigment patches present posteriorly to low-pigmented nasal depressions. Iris silver, with scattered dark patches. Two narrow dark lines originate at dorsal pole of pupil and extend ventrally. Symmetrical black bands over dorsum to gas-filled cavities at the origin of the tail musculature. A dark brown line runs along the top of the tail musculature between dark bands of gas-filled cavities. R2 (Fig. 2) in the body almost covered with iridiophores, giving it a characteristic silvery shine, and black color patches present on this silver region. Reduced pigmentation in the tail musculature and tail fins. Ventrally, heart visible, cream colored, at margin of R1 and R2.

Variation. There is a substantial amount of variation in the lower lip in tadpoles of different developmental stages, and sometimes even within a given developmental stage. At Stage 25 (early stage) for instance, there is a single pair of scallops on the lower lip but these develop into six very distinct papillae (three pairs) by late Stage 25. At Stage 30, the scallops are distinct and there is little variation within the stage. By Stage 35, the scallops are not clearly discernible (and there is little variation within the stage; Fig. 8).The tail-fin shape changes from a simple long triangular shape (Stage 25) to a more complex shape with two crests on the ventral tail fin (anterior crest deeper and crest in middle of tail shallower; Stage 35).

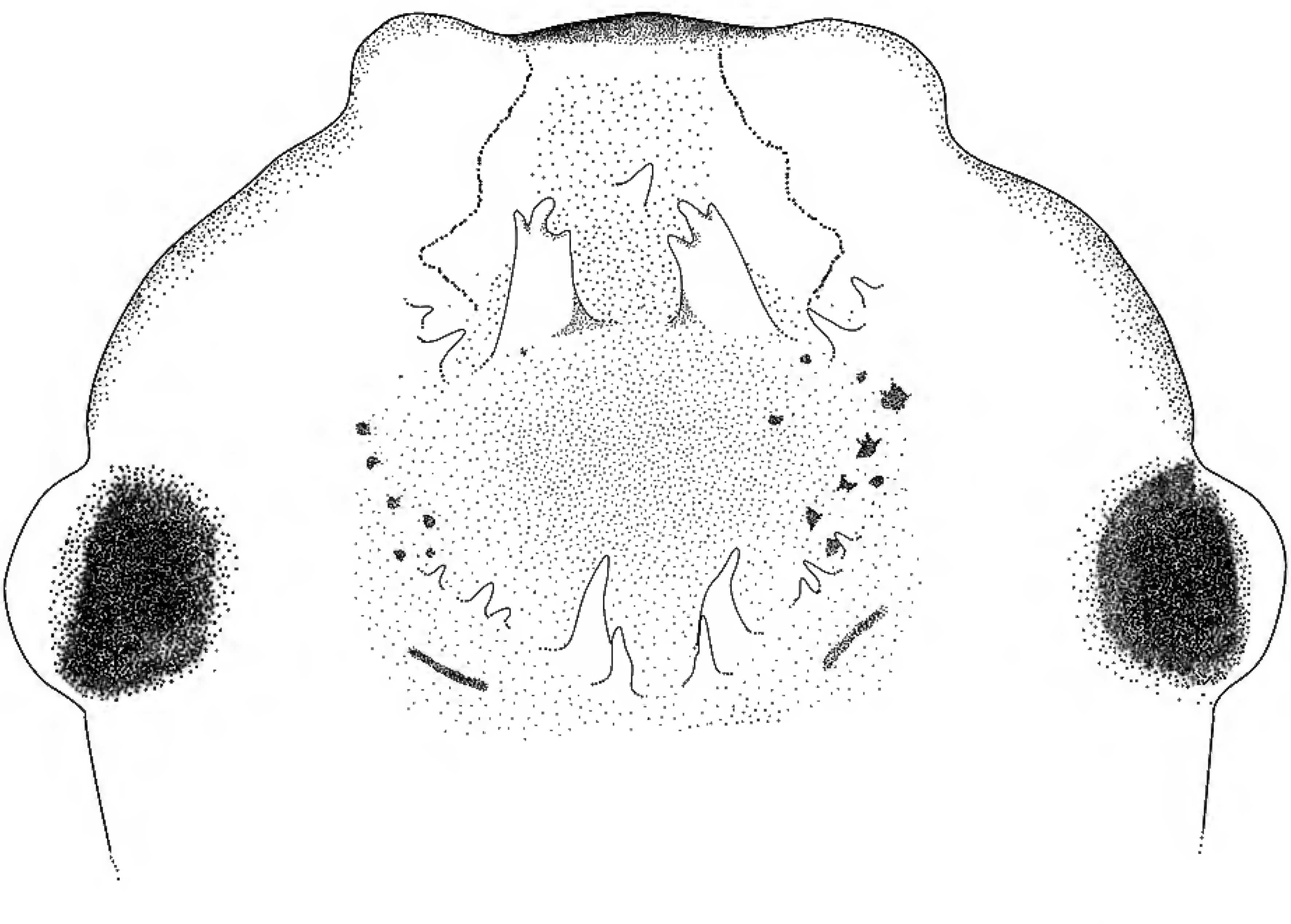

Figure 7. Dorsal buccal morphology of a *Microhyla rubra* tadpole (Stage 35). Scale bar, 1 mm.

Measurements (mm). bh = 5.25; bw = 5.93; ed = 1.26; ht = 5.50; lf = 2.54; nn = 1.12; np = 2.66; pp = 5.54; rn = 1.20; ss = 7.58; su = 7.66; svl = 7.99; tl = 27.04; uf = 0.85; vt = 19.05; tmh = 2.31, and tmw = 1.68. Measurements of tadpoles in Stages 26, 31, 33, and 35 are presented in Table 1.

Ecological notes. We observed a group of late-stage embryos (almost ready to hatch) on the surface of an open pool of water. The pool was man-made (probably excavated clay for brick-making forming the depression which then filled with water), isolated from other water bodies, and exposed to direct sunlight. The pool shore was lined with small shrubs and visible submerged terrestrial shrubs and vegetation, suggestive of recent inundation (Fig. 1). The pool apparently had been filled with rainwater, and was likely ephemeral. The maximum depth of the pool was about 50 cm (most areas shallower) with an area of approximately 100 m^2. Water quality of the pool (9:50 am): temperature = 26.3 °C; dissolved oxygen = 0.92 mg/l; pH = 6.68; conductivity = 87.8 µS; salinity = 0; $(NO_3^-)N$ = 0.524 mg/l; $(NH_4^+)N$ = 0.46 mg/l; free NH_3 = 0.56 mg/l; fluoride = 0.8 mg/l; total hardness = 275 mg/l; SO_4^{2-} = 0 mg/l. A total of 410 early stage, whitish-gray embryos were observed and several were collected for study.

The larvae of several anuran species were observed in syntopy with the *M. rubra* tadpoles: *Polypedates maculatus*, *Microhyla ornata*, *Fejervarya limnocharis*, a bufonid tadpole of an unidentified species, and *Sphaerotheca rolandae*.

Discussion

Tadpoles of *Microhyla rubra* lack keratinized mouth parts and have a dorsoterminal mouth. Dorsoterminal mouths are not observed among New World microhylid tadpoles, but within old world microhylid tadpoles, both terminal and dorsoterminal mouthparts are observed (Donnelly et al. 1990).

Donnelly et al. (1990) highlighted several microhylids species that lack flaps of the upper lip (*M. rubra* lacks flaps on the upper lip) and other species that lack flaps are *Glyphoglossus molossus*, *Kalaula borealis*, *K. rugifera*, *K. verrucosa*, *Metaphrynella pollicaris*, *Microhyla achatina*, *Mi. anectens*, *Mi. okinavensis*, *Mi. heymonsi*, *Mi. pulchra*, and *Mi. zeylanica*. *Microhyla zelanica* is a Sri Lankan endemic whose tadpole was described by Kirtisinghe (1957); though he did not describe the oral flaps explicitly, his figure shows flaps to be absent on the upper lip. Kirtisinghe (1957) described tadpoles of *M. rubra*, which lack flaps on the upper lip.

Microhyla rubra have six papillae (scallops) on the lower lip but number varies with developmental stage.

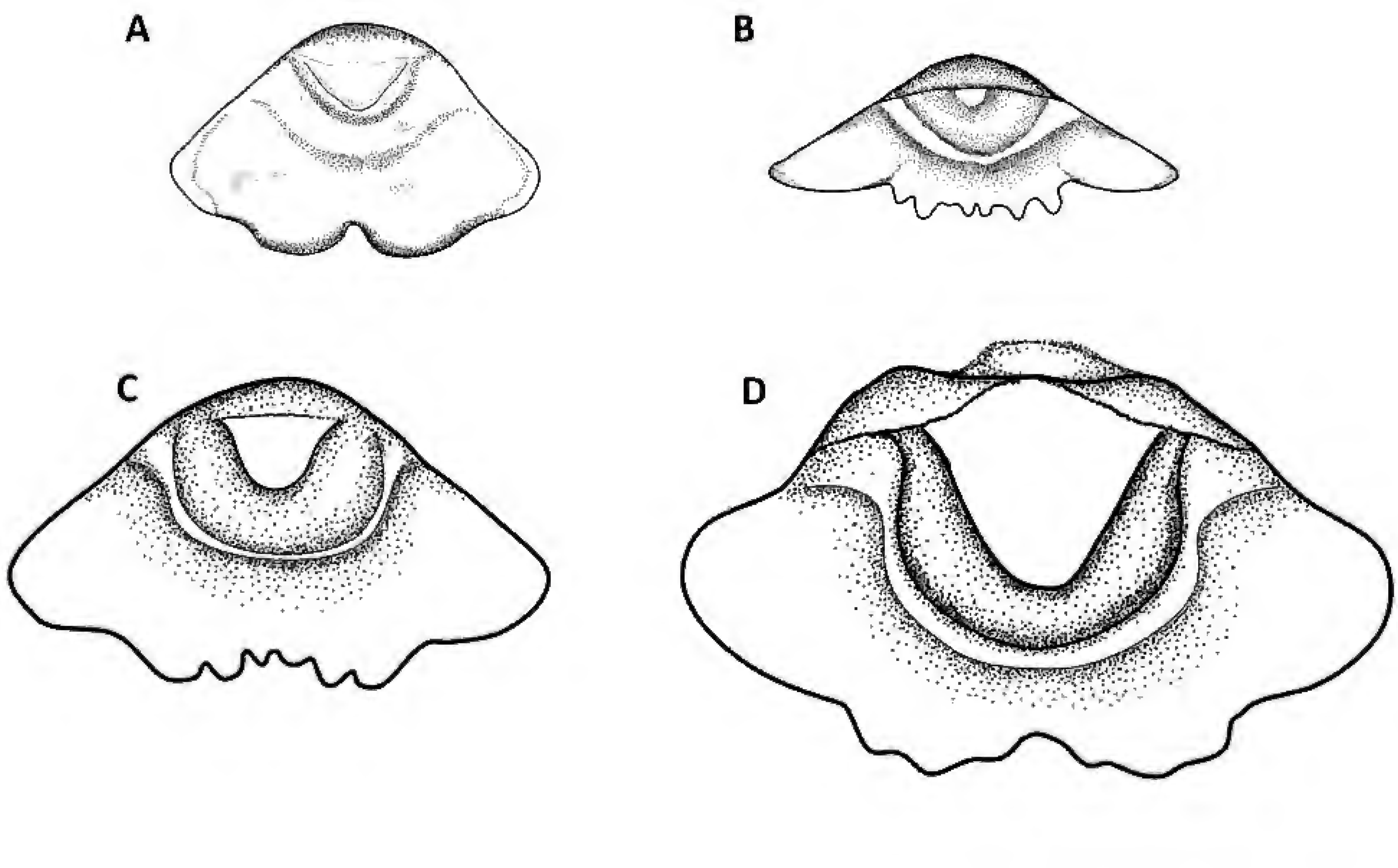

Figure 8. Variation in oral flaps of *Microhyla rubra* tadpoles at various stages of development (A) Gosner stage 25 – early; (B) Gosner stage 25 – late; (C) Gosner stage – 30; (D) Gosner stage – 35. Scale bar, 1 mm.

However, in Kirtisinghe's (1957) diagram of *M. rubra*, the scallops are not discernible (not mentioned as papillae or scallops by Donnelly et al. 1990), but there appears to be more than two, and Kirtisinghe apparently illustrated a late stage (Stage 35 or later) tadpole. Kirtisighe's (1957) diagram of the lower lip of *M. zeylanica* shows five well-distinguished conical papillae. Lower lip papillae, surprisingly, are reported in few other species of microhylids (Donnelly et al. 1990).

The whip-like tail-end flagellum has been reported from nine species of microhylids (Donnelly et al. 1990). Parker (1934) and Kirtisinghe (1957) mention the flagellum in *M. rubra*. Parker (1934) correctly asserts that the flagellum enables these tadpoles to maintain their position in water. In aquaria we observed the tail being waved occasionally but the flagellum being waved almost continuously. These tadpoles have the ability to move the very tail tip, helping maintain their position in the water, probably helping the tadpoles to conserve energy and reducing surface disturbance that may be attractive to predators. Further, buoyancy is perhaps assisted by the air-filled dorsolateral cavities (or developing lungs) in the body (in R2).

A nasolacrimal duct is apparent in Stage 35 tadpoles. Lehr et al. (2007) argue that it is present in all tadpoles, but only apparent in near metamorphs. Enough information has not been gathered to support or refute that this duct is present in all tadpoles, but it was only apparent in *M. rubra* tadpoles at an advanced stage. Lehr et al. (2007) recommend that a better description for this character would be to observe whether or not the nasolacrimal duct is pigmented. In *M. rubra*, it is apparent only because it is relatively unpigmented, compared to the background, but in some species it may be apparent because it is more pigmented, compared to the background. We therefore suggest that when this character is assessed, the background pigmentation (relative to the pigmentation on the duct) should be considered.

External nares are open only in late stage microhylid tadpoles (McDiarmid and Altig 1999). Kirtisinghe (1957) highlights this for *M. rubra* and we confirm. We observed that external nares open very late, after front limbs emerge at Gosner stage 41. Nares opened forming a rim by the nasal opening in Gosner stage 42.

Kirtishinge (1957) states that toes are fully webbed in tadpoles. We observed that toes were mostly webbed in tadpoles (having toes), but saw that webbing rapidly diminishes by Gosner stage 42. Webbing is vestigial, conforming to the extent seen in adults, by the one-month old froglet stage (when the study ended).

The ventral tail fin of *M. rubra* is deeper than the dorsal tail fin. Nelson (1972) mentions that *Microhyla*

Figure 9. Newly emerged froglet of *Microhyla rubra* (SVL: 8.31mm.

have deeper ventral fins, and highlights *M. pulchra* and *M. rubra* as having much deeper fins. We confirm this assertion.

The notch apparent on the upper lip, in late stage (Gosner 35), is not depicted in Kirtisinghe (1957).

The spiracle in *M. rubra* opens mid-ventrally, and the opening of the spiracl M. ornata e is crescent-shaped. This shape is most easily observable in live tadpoles (Fig. 3C).

There is substantial variation in oral flaps at various developmental stages (Fig. 8). Most of this variation is portrayed in the amount and prominence of scallops on the lower flap (or labium). Variation within Gosner stages is apparent, especially for early Gosner stages. For instance, at Gosner stage 25, early-stage larvae have only two relatively large scallops on each flap, but by late-stage, size of the individual scallops decreases and number increases up to six. By Gosner stage 30, number of scallops remains at six, however, by stage 35, prominence of these are reduced, and in some specimens, depending on the mouth position upon preservation, it can be difficult to distinguish these scallops. Hence, when tadpoles are described, it is important to note the development of a character periodically over several developmental stages, rather than highlighting characters at only a single stage (often Gosner stage 35 is used), especially from only a single individual.

Rao (1918) described *M. rubra* as being nontransparent, but experience in the field with *M. rubra* tadpoles has shown they are almost as transparent as *M. ornata* tadpoles. Rao (1918) comments that Ferguson (1904) had confused the larvae of *M. ornata* and *M. rubra*. However, without knowing the stage at which the comparisons were made (there was no general agreement on staging tadpoles at the time), it is difficult to endorse Rao's assertion. However, we disagree with Rao's statement that *M. rubra* tadpoles are "not transparent." Kirtisinghe's (1957) description of the Sri Lankan *M. rubra* refers to them as "mostly transparent." However, preservation reduces the transparency of late-stage tadpoles in both species.

We raised *M. rubra* for a month beyond metamorphosis. This enabled us to determine unequivocally that the tadpoles raised were verifiably *M. rubra* (Fig. 9).

Although we sampled for aquatic tadpoles in all habitat types (e.g., man-made irrigation tanks, wells, streams, rivulets, and paddy fields) we only found *M. rubra* tadpoles in ephemeral pools. Several issues could be important for their absence: flowing water, water chemistry, the ephemeral nature of the water body, and predators. The more permanent water bodies are occupied by predatory fish such as *Channa* (Snakehead), *Mystus* (Catfish), and smaller cyprinid fishes that we have observed feeding on the various life history stages of most amphibians. In these ephemeral habitats, such large aquatic predators are absent (Skelly 1996; Eterovick and Barata 2006).

Flowing water makes it impossible to have surface-floating eggs for any length of time. However, the problem with non-flowing water is paucity of oxygen, especially when biomass within the water body is high. One way of overcoming this is to have surface eggs, which not only provides for better access to oxygen, but to higher temperatures, which together facilitate rapid development. Rapid development is important when living in ephemeral pools, to escape desiccation before development is complete (Skelly 1996). The temperatures in the shallow pool (where we found these eggs) were high (26.3 °C) and oxygen levels low (0.92 mg/l; measured at 9:50 am).

Tadpoles that we raised in the laboratory took 77 days to metamorphose. Days to metamorphose in the wild might be lower as the temperature in its habitat is higher (day time lab temperature = 22-24 °C; day time habitat temperature 26-30 °C), probably accelerating development.

M. rubra tadpoles live in water close to the surface and feed on plankton and suspended food particles.

Many aquatic habitats in the dry zone of Sri Lanka are polluted to some degree, and ephemeral pools provide a refuge for amphibians to breed. Activity of the numerous tadpoles together with the decaying biomass conceivably could drive up the unbound ammonia and nitrate concentrations, while reducing the dissolved oxygen concentration. A combination of indiscriminate biocide use, overuse of fertilizer, habitat alteration, and urbanization has changed the freshwater habitats of Sri Lanka dramatically (Steele et al. 1997). Habitat of early-phase paddy fields could conceivably provide an excellent environment for *M. rubra*, although we did not find them there, conceivably due to the overuse of fertilizer and biocides. Sri Lanka-Western Ghats is one of the most populous of the 34 global biodiversity hotspots and this has created a significant impediment to preserving habitats and moderating rapid changes in inimical land use patterns.

Water chemistry of the ephemeral pools indicates that they are not highly polluted. Although free ammonia is fairly high within the pool, bound ammonia (NH_4^+) N, conductivity, salinity, and sulphate-ion concentrations were low. Further studies are needed to assess the tolerance levels of tadpoles and the role of ephemeral pools in providing a refuge for tadpoles of various species.

Although human activities inadvertently create a few ephemeral pools for frogs, they may be drained, filled, and levelled in a surprisingly short period of time. There is a small chance for breeding populations of frogs to establish themselves and survive in these types of habitats. Special consideration (different from those practiced in preserving and managing the forest habitats of Sri Lanka) is needed in managing amphibians of the dry zone of Sri Lanka.

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Figure 1. *Oligodon arnensis*, a non-endemic colubrid snake species found in the lowlands throughout the island, except the dry southeastern parts. *Photo by Indraneil Das.*

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Conservation of biodiversity in a hotspot: Sri Lanka's amphibians and reptiles

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Abstract.—**Sri Lanka is a continental tropical island that is considered a hotspot for amphibian and reptile diversity. During the last decade herpetological research has substantially improved our knowledge of species and their taxonomic status. However, additional work is needed on ecology and population viability within the framework of human impacts on natural ecosystems. These human induced activities have led to severe fragmentation of formerly continuous forest in the wet zone and central hills of Sri Lanka, where most endemic and threatened species occur. Here I discuss current development in biodiversity issues regarding the Convention on Biological Diversity and their effects on the future of herpetofaunal conservation in Sri Lanka. To better understand Sri Lanka's conservation challenges and threats I discuss the following topics: Sri Lanka's biogeography; its extant ecosystems and landscapes along with the changes resulting from patterns of human settlement; human population growth and its concomitant impact on natural ecosystems; and a brief history of herpetological studies in Sri Lanka. Further, I discuss major conservation issues related to the ecoregional and hotspot approach to biodiversity conservation, the IUCN species lists, and the institutional framework in biodiversity conservation. Finally, I propose an integrated action plan for the conservation of Sri Lanka's herpetofauna that includes cooperation between relevant institutions, future scientific studies, education, capacity development, *in situ* and *ex situ* conservation, and encouragement of increased collaborative effort in biodiversity conservation with the Western Ghats of southern India.**

Key words. Sri Lanka, biogeography, history of herpetological research, biodiversity conservation, biodiversity hotspot, amphibians, reptiles, action plan

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Introduction

The World Summit on Sustainable Development, held in Johannesburg in 2002, and the United Nations General Assembly endorsed a "2010 Target" based on a decision of the 6th Conference of the Parties to the Convention on Biological Diversity. The target was to achieve, by 2010, a significant reduction of the current rate of biodiversity loss at global, regional, and national levels as a contribution to poverty alleviation and to the benefit of all life on Earth (SCBD 2010). The 2010 target and its 21 subtargets have not been met globally despite partial local achievements (SCBD 2010). To scale up efforts to deal with continued biodiversity loss and other biodiversity issues the United Nations proclaimed 2010 the "International Year of Biodiversity." The main objectives of the Year were to (source: Secretariat of the Convention on Biological Diversity):

- Enhance public awareness of the importance of conserving biodiversity and underlying threats to biodiversity.
- Raise awareness of accomplishments to save biodiversity by communities and governments.
- Promote innovative solutions to reduce threats to biodiversity.
- Encourage individuals, organizations, and governments to take immediate steps to halt biodiversity loss.
- Initiate dialog between stake holders for steps taken in the post-2010 period.

In October 2010 the 10th meeting of the Conference of the Parties to the Convention on Biological Diversity (COP 10) took place in Nagoya, Japan. Efforts in Nagoya were

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underpinned by earlier reports on biodiversity such as the biodiversity synthesis report of the Millennium Ecosystem Assessment (MEA 2005) and Global Biodiversity Outlook 3 (SCBD 2010). The COP 10 meeting was a breakthrough in the conservation of biological diversity. Meeting participants adopted an outstanding measures package including: (1) a strategic plan for biodiversity and the Aichi biodiversity targets; (2) the Nagoya protocol on access to genetic resources and fair and equitable sharing of benefits arising from their utilization; (3) a strategy for resource mobilization; (4) a continuation of the process of establishing an intergovernmental platform on biodiversity and ecosystem services; and (5) the recommendation to the United Nations General Assembly to declare 2011-2020 the UN Decade on Biodiversity.

One key outcome of the COP 10 meeting was the recommendation to globally update the national biodiversity strategies and action plans (NBSAPs). Within the process of updating, amphibians and reptiles could get more attendance within the overall framework of preserving Sri Lanka's unique biodiversity. The relevance of an adequate consideration of Sri Lanka's herpetofauna for NBSAP is that Sri Lanka is recognized as a global amphibian hotspot (Meegaskumbura et al. 2002; Pethiyagoda and Manamendra-Arachchi 1998) as well as a mega-hotspot of reptile diversity (Somaweera and Somaweera 2009).

Moreover, especially since the release of the 4th Assessment Report of the IPCC (2007; see: www.ipcc.ch) and the so-called "Stern Review" (Stern 2006), the global political leadership and the UN have increasingly focused on discussions of global climate change and its effects on human well-being and the future of Earth's biological diversity. Collectively these most recent developments seem to set the stage for new discussions about conserving Sri Lanka's biodiversity and mitigating the impacts of—and adapting to—global climate change. The herpetofauna of Sri Lanka, being an essential component and an indicator of the overall health of Sri Lanka's ecosystems, plays a crucial role in contributing both to the sustenance of the country's wealth in life forms and ecosystem services provided to the local human population.

This paper is future-oriented and action-oriented with regard to the long term preservation of Sri Lanka's herpetofauna. Here I provide a holistic picture of what is needed to strengthen conservation efforts at all levels, including research, education, partnership, and policy. These conservation efforts should be accomplished first and foremost at the national level but also integrated into subregional (e.g., jointly for the Western Ghats of India and Sri Lanka biodiversity hotspots), regional, and global efforts toward amphibian and reptile conservation. These conservation efforts should be recognized in context to human impact on natural ecosystems and global climate change. Moreover, they should be part of Sri Lanka's overall effort towards biodiversity conservation and sustainable use of its ecosystem services (for an overview see TEEB 2010). More specifically, this paper outlines: (1) aspects of the biogeography of Sri Lanka; (2) the history of herpetological research and our current knowledge base; (3) conservation issues; and (4) a proposal intended to contribute to further discussions and elicit appropriate measures for future sustainable conservation of Sri Lanka's herpetofauna.

The tropical continental island of Sri Lanka—A note on biogeography

Historical remarks

Based on detailed studies of the flora and fauna of India over thirty-five years ago, attempts were made to subdivide the Indo-Ceylonese region into biogeographical subregions and other units (e.g., Mani 1974). The first zoogeographical studies, carried out in the 19th century, were based on distributional patterns of terrestrial mollusks (Blanford 1870), reptiles (Günther 1858, 1864), and birds (Jerdon 1862-1864). The definition of floristic regions began in the middle of the 19th century (e.g., Hooker and Thomson 1855; Clarke 1898) and the beginning of the 20th century (e.g., Prain 1903; Hooker 1906).

Collectively, these studies revealed a strong similarity between Sri Lanka and neighboring India, especially with regard to the more humid regions of the Western Ghats and southwestern Sri Lanka. Repeatedly, south India and Sri Lanka were seen as a single biogeographical subunit comprising two major pairs of similarities, i.e., the Malabar Tract, southwestern and hill regions of Sri Lanka, southeastern India, and drier parts of Sri Lanka (e.g., Bhimachar 1945; Phillips 1942; Wait 1914). These patterns of similarity encompass the majority of plant and animal species, particularly the herpetofauna discussed here (for an overview of the biogeography of the reptiles of south Asia, see Das 1996a).

Geological past

The geological history of Sri Lanka is subdivided into the following phases (after Dietz and Holden 1970; Keast 1973; McKenna 1975; Pielou 1979; Raven and Axelrod 1974):

- Pre-drift phase where Sri Lanka and India were part of Gondwana (> 100 MYBP).
- Drift phase ending with the collision of the Indian plate and the Asiatic continent (66 and 45 MYBP).
- Miocene epoch (ca. 25 MYBP), Sri Lanka's separation from India, following a series of complex

tectonic movements, which began in the Jurassic (see Cooray 1984; Katz 1978; Swan 1983).

- Quaternary epoch (two MYBP to present), eustatic sea level changes, climate cycles, and repeated formation of land bridges between India and Sri Lanka, in the Palk Strait region.

Similarities observed between flora and fauna of Sri Lanka and India are linked to having been part of the Indian plate and an isolated unit in the Tethys Sea, after its separation from the Gondwanan landmass and before it collided with Asia. Additionally, the biogeographical evolution of India and Sri Lanka was certainly shaped by the global K-T event, the Deccan volcanism (Cretaceous to Eocene; Wadia 1976), the orogenic processes leading to formation of the Himalayas, the development of the monsoon pattern, and floristic and faunistic exchanges between the Indian plate and Asia (early Tertiary 45-25 MYBP), particularly with southeast Asia (see Klaus et al. 2010). This phase was followed by Quaternary climate fluctuations and eustatic changes in sea level leading to repeated formation of land bridges between India and Sri Lanka (Palk Strait region; for pollen data see Premathilake and Risberg 2003). During Quaternary sea level maxima, when Sri Lanka was isolated from India, biogeographical patterns most likely changed independently from India. The Quaternary is often seen as the decisive period for shaping the present plant and animal distribution patterns in Sri Lanka (e.g., Erdelen 1993a; Erdelen and Preu 1990a). "Time lags" between eustatic sea level changes, climate change, and the "reaction" of plant and animal species may explain some of the similarities among rain forest species in southern India and Sri Lanka (Erdelen and Preu 1990a).

Many unanswered questions exist regarding the biogeographical evolution of Sri Lanka's flora and fauna (for more recent analyses see Biswas 2008; Biswas and Pawar 2006). Most speciation events among amphibians and reptiles pre-date the Quaternary period. This notion is supported by several recent papers on genetic divergence within rhacophorid frogs. A study on rostral horn evolution of the endemic genus *Ceratophora* suggests a Miocene origin of the genus and several speciation events dating approximately between 12.6 and 2.4 MYBP (Schulte II et al. 2002). A similar situation was reported for the remarkable radiation of Sri Lanka's freshwater crabs (50 endemics from a total of 51 species for the island; Beenaerts et al. 2010). The uropeltid snake species of southern India and Sri Lanka may have been separated for a period longer than 10-15 MYBP (e.g., Cadle et al. 1990). In fact, many of the speciation events thought to have been associated with different phases of the Pleistocene are much older and likely the result of speciation events in the Tertiary (e.g., see Maxson 1984, Roberts and Maxson 1985a, 1985b, for Australian frogs).

Speciation rates may have varied within groups such as birds in Sri Lanka and India (Erdelen 1993a). Migration patterns into and out of the Indian-Sri Lankan region likely differed substantially among and within taxa (for Cincidelid beetles, see Pearson and Ghorpade 1989), and exchanges of floral and faunal elements need not have been symmetric but may show a marked asymmetry if India and neighboring regions are compared. The results of these highly variable processes are rather complex extant patterns of geographic distribution. Further studies are essential for a more complete understanding of the major evolutionary processes that formed Sri Lanka's flora and fauna. The basis of such studies would be the understanding of undisturbed, "pristine" geographic distribution patterns allowing for the reconstruction of historical processes producing Sri Lanka's biodiversity.

Extant ecosystems and landscapes

Sri Lanka's rich biodiversity is reflected in its diverse extant ecosystems and landscapes. Ecosystems may be classified into the following (for more details and references, see Dela 2009; Gunatilleke et al. 2008; Ministry of Forestry and Environment 1999):

- Forest and grassland
- Inland wetland
- Coastal and marine
- Agricultural
- Urban

The most important ecosystems for amphibians and reptiles are certainly the first two categories, especially if minimally disturbed by humans, although coastal and marine ecosystems are important to reptile taxa like marine turtles and crocodiles. Agricultural and urban systems may provide habitats for species with broad habitat requirements, especially those that live commensally with humans.

Often underestimated in their role of maintaining viable populations are secondary forests or, more generally, "novel ecosystems." These are described as heavily influenced by humans but not under human management, or "lands without agricultural or urban use embedded in agricultural and urban regions" (Marris 2009). More than 90% of amphibian species in Sri Lanka occur in secondary forests, highlighting the importance of novel ecosystems (R. Pethyiagoda, pers. comm.). Long-term conservation efforts should consider the landscape mosaic of Sri Lanka, which comprises ecosystems that vary in geographic extent and human perturbation. System interlinkages and scale may be essential parameters for understanding and managing such diverse environments (Erdelen 1993b).

Vegetation maps for Sri Lanka date to the 1930s. Based on the three climatic zones of the island, namely the wet, intermediate, and dry zones, the National Atlas of Sri Lanka distinguished 11 different types of plant communities (Somasekaram 1988). For analyses of fau-

nal distribution patterns in Sri Lanka a simplified subdivision into seven zones with six different types of natural vegetation has been frequently used (e.g., Crusz 1984, 1986; Crusz and Nugaliyadde 1978; Erdelen 1984, 1989, 1993a).

Based on distribution data for angiosperm plants, recent studies have shown that within these major vegetation units 15 floristic regions may be distinguished, located largely within the wet zone and the mountain region of Sri Lanka (Ashton and Gunatilleke 1987; Gunatilleke and Gunatilleke 1990). Even within these floristic regions, forest communities show a patchy distribution, sometimes with rather different species compositions (Gunatilleke and Gunatilleke 1983). Individual hills may have unique forest communities (Abeywickrama 1956), for example Hinidumkande in the southwestern part of the wet zone. The rainforests of this mountain show a striking concentration of endemic tree species (Gunatilleke and Gunatilleke 1984). Another well-known example is Ritigala, a 766 m high mountain in the northern part of Sri Lanka's dry zone. Although located in the dry zone this mountain contains endemic plant species characteristic of the wet zone and species which otherwise occur only in the mountain region and not elsewhere in the dry zone. Some plant species are endemic to Ritigala (for details see Jayasuriya and Pemadasa 1983; Jayasuriya 1984).

Although numerous attempts have been made to explain these highly localized concentrations of endemic species (see Willis 1916, for one of the earlier discussions), we still do not know whether, and to what extent, these are possibly a result of Quaternary dynamics of vegetation patterns (related to glacial and interglacial cycles and associated climate regimes). Moreover, it is not clear whether, and if so to what extent, such small-scale mosaics in vegetation patterns are reflected in endemic animal taxa, and thus may need more attention as part of the overall efforts of biodiversity conservation in Sri Lanka (see Raheem et al. 2009).

When we try to reconstruct the evolution of Sri Lanka's biota and its relationship to Indian flora and fauna, "biogeographical reconstruction" is increasingly hampered by anthropogenic alterations of habitats. Relatively undisturbed ecosystems and associated distribution patterns within a floral or faunal setup should be the basis for reconstructing historical events, which shaped the extant composition of Sri Lanka's flora and fauna. Only if the spatio-temporal dynamics of anthropogenic effects on natural ecosystems are well-known and documented will such a reconstruction process be facilitated and the "true" patterns and underlying historical processes involved be discovered.

Modern humans settled in Sri Lanka between 75,000 and 125,000 YBP or earlier (Deraniyagala 1993). Estimates of human densities during different periods of human history in Sri Lanka would provide indirect evidence of potential impacts on natural vegetation and associated fauna. During the pre-historic phase, between 75,000 YBP and 10,000 YBP, when humans were essentially subsistence hunters and food gatherers, the wet zone and hills of Sri Lanka were already settled, although in low densities. Deraniyagala (1993) provides an estimate for the wet zone during this phase of up to 10,000 YBP of some 0.1 individuals/km^2. The transition period (pre-historic to proto-historic and early historic phases), saw high human densities in the dry zone increasing during the Singhalese high culture (beginning ca. 200 BC), a time associated with the advent of Buddhism in Sri Lanka. During the Anuradhapura Period (250 BC-1017; first urbanization phase) and the Polonnaruwa Period (1017-1235) extensive systems of irrigation tanks were established in the dry zone for rice cultivation (see Abeywickrama 1993).

During the Late Historic Phase, from the 14th century onwards, the political, economic, and cultural centers shifted from the north-central, eastern and southeastern parts of the island towards the lowlands of the wet zone, the central highlands, and into the extreme northern parts of Sri Lanka (Erdelen 1993a). This restructuring process was associated with the downfall of high cultures in the dry zone and the beginning of the colonial periods (Portuguese, Dutch, and British). During the British Period (1796-1948) in particular, massive impacts on the natural forests of southwestern Sri Lanka and the central hills were recorded. The introduction of plantation industry (cinchona, coffee, tea, and rubber) and infrastructural measures caused changes for these regions. Following Sri Lanka's independence (1948), there was a period of intensified man-made alterations to the natural ecosystems of Sri Lanka, with the objective of supporting both a rapidly increasing population and an accelerated economic growth (Erdelen 1988b, 1993; Erdelen and Preu 1990b; Erdelen et al. 1993; Ministry of Forestry and Environment 1999).

The population of Sri Lanka has tripled in size in some 60 years, from 7.2 million inhabitants in 1948 to over 21 million in 2011. Population density, formerly being highest in the dry zone of Sri Lanka, has now reached over 500 individuals/km^2 in the wet zone (Dela 2009; see Cincotta et al. 2000, with regard to global biodiversity hotspots). These historical processes have led to a considerable change in the distribution of natural vegetation in Sri Lanka (see Erdelen 1996). More extensive areas under natural forest cover are essentially found in the dry zone. The forests of the wet zone and the central hill range have become highly fragmented. No continuous primary forest cover remains from sea level to over 2,500 m of the central hill range. Note these statements refer to "vegetation" and major types of ecosystems but do not reflect the fine-scale analysis and implications these changes might have for plant and animal species/populations and their long-term viability.

Analysis of the following questions may be useful in gaining a better understanding of processes at relevant scales and for subsequent appropriate conservation measures:

1) Concomitant with anthropogenic impacts on natural vegetation: have plant communities changed significantly both in structure, and therefore, in microhabitat and microclimatic conditions, as well as in species composition?

2) If so, at what scale has this happened and what does the extant mosaic of differentially impacted plant ecosystems look like?

3) How do distribution patterns of amphibians and reptiles relate to vegetation or plant community patterns? If they do, what is the "reference" equivalent with regard to vegetation type or "structural" habitat parameters against which distribution patterns could be calibrated?

4) What are the projections of population or species viabilities if questions 1-3 are analyzed simultaneously?

5) What would be the implications of such analyses for biodiversity conservation measures, specifically in regards to amphibians and reptiles?

In conclusion, we need a better understanding of proximate and ultimate factors (i.e., knowledge of the crucial ecosystem or habitat parameters) decisive in the long-term persistence of amphibian and reptile populations. These factors vary intrinsically with species' ecologies and are shaped by human impacts on natural ecosystems and habitats. These concepts need to be taken into account for monitoring long-term population trends in Sri Lanka.

History of herpetological research in Sri Lanka

Herpetological research has a long history in Sri Lanka (de Silva 2001) and has been part of the general history of biodiversity exploration in Sri Lanka (Pethiyagoda 2007). Interest during the British period (1796-1948) was mainly in horticulture for the introduction of commercially-used crops and for exporting plants from Sri Lanka. Except for earlier work by French workers and scientists associated with the British Museum in the 19th century, the focus on the fauna of Sri Lanka began with the establishment of the Colombo Museum in 1877. For the most part, until about the time of independence, it would be amateurs who led efforts to explore the island's herpetofauna (Pethiyagoda 2007).

A detailed analysis of factors shaping herpetological research in Sri Lanka would be worth undertaking but is beyond the scope of this paper. The most recent scientific research efforts have been vital for a more thorough understanding of the herpetofauna of Sri Lanka, especially in regard to the number of species on the island as well as their taxonomic status. It is clear from these studies that several species have become extinct in recent times and more work is needed to preserve Sri Lanka's herpetofaunal diversity into the future (see below).

Amphibians

Species lists for amphibians of Sri Lanka have been compiled since the 19th century. These were first published within the framework of regional compilations such as the works of Günther (1864) and Boulenger (1890). The first lists of exclusively Sri Lankan amphibians were published by Kelaart (1852) and Haly (1886a) followed by numerous publications on individual amphibian taxa (for compilations see Dutta and Manamendra-Arachchi 1996; Erdelen 1993a). In the 1950s, de Silva published a species list for Sri Lanka, including the specimens housed in the Colombo Museum (de Silva 1955). This

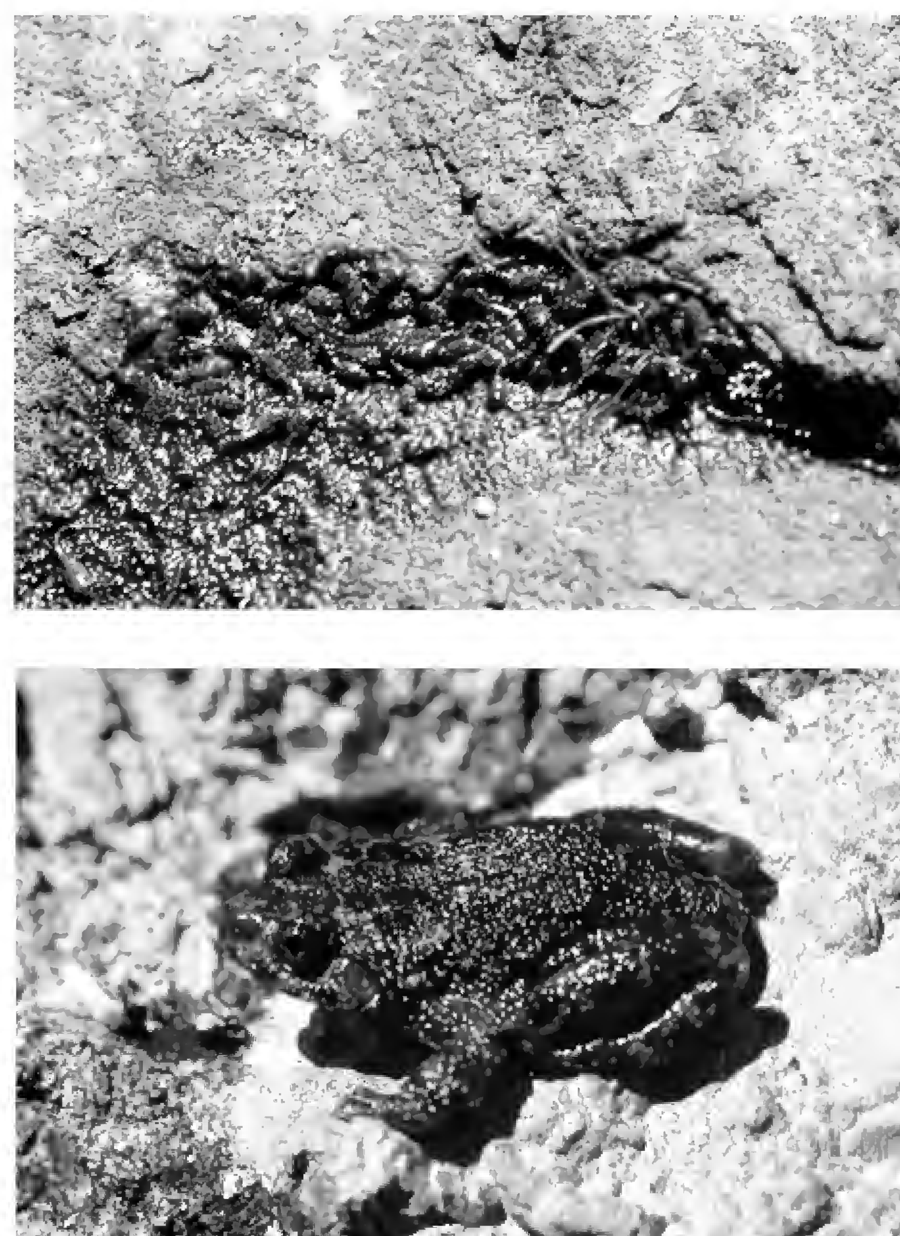

Figure 2. Tadpoles (top) and adult specimen (bottom) of *Nannophrys marmorata*, an endemic species restricted to the Knuckles range; Critically Endangered. Mainly found under boulders on wet, flat, rocky surfaces (Dutta and Manamendra-Arachchi 1996; confirmed by own observations). The genus is endemic to Sri Lanka, comprising four species, one of them (*N. naeyakai*) described only in 2007 (Fernando et al. 2007). *Photos by Walter R. Erdelen.*

publication was followed by Kirtisinghe's (1957) monograph *The Amphibia of Ceylon*. Thereafter, and repeatedly, checklists for the amphibians of Sri Lanka were compiled (Kotagama et al. 1981; de Silva 1994, 1996, 2001). In parallel, taxonomic revisions were undertaken for the first time (for details see Dutta and Manamendra-Arachchi 1996 and Erdelen 1993a). Dutta (1985), in his Ph.D. dissertation, updated information on the amphibians of Sri Lanka and India and in 1996 published the first modern account of the amphibian fauna of Sri Lanka (Dutta and Manamendra-Arachchi 1996). Possibly the first indication that Sri Lanka may be home to many more amphibian species is indicated in publications from the mid-90s where new amphibian species were described (e.g., Fernando et al. 1994; Manamendra-Arachchi and Gabadage 1996). As Dutta and Manamendra-Arachchi (1996) wrote in their introduction: "We expect there to be a dramatic increase in the diversity of amphibians of Sri Lanka, especially among the Rhacophoridae." Indeed in 2002 detailed information on Sri Lanka's outstanding amphibian diversity was published in an article in *Science* (Meegaskumbura et al. 2002) indicating that rhacophorid frogs may comprise over 100 species in Sri Lanka. In this paper it was stated that "Sri Lanka's amphibian diversity (about 140 species on an island of 65,610 km^2) now approaches or exceeds that of many amphibian diversity hotspots and is comparable to those of tropical islands an order of magnitude larger, such as Borneo (746,300 km^2; 137 species), Madagascar (587,000 km^2; 190 species), New Guinea (775,200 km^2; 225 species), and the Philippines (299,800 km^2; 96 species)."

Meanwhile, species numbers for amphibians in Sri Lanka stand at 111, of which some 90% are endemic (Fig. 2; for regularly updated information see: http://amphibiaweb.org). Still more species await description and the percentage of endemism is expected to rise, as seen in the 2007 list of threatened fauna and flora of Sri Lanka which already mentions 106 amphibian species of which 90 (85%) are endemic (IUCN Sri Lanka and MoENR 2007).

Reptiles

The earliest publications on Sri Lankan reptiles are included in those of a more general nature already mentioned above. Ferguson (1877) and Haly (1886b, 1891) compiled information about reptiles in collections of the Colombo Museum. Most famous have been the publications of P. E. P. Deraniyagala (for an overview, see de Silva 1977). He published three outstanding volumes on the turtles and crocodiles, lizards, and snakes of Sri Lanka (Deraniyagala 1939, 1953, 1955). At that time, the only comparable publications were Smith's *Fauna of British India* (Smith 1931, 1935, 1943) and Taylor's work on individual taxa (Taylor 1947, 1953b) and his overviews of the Sri Lankan snakes, skinks, and lizards (Taylor 1950a, 1950b, 1953a).

This period was followed by a number of systematic/taxonomic and ecological studies of individual taxa (overviews in Erdelen 1993a; de Silva 2006). De Silva (1998a, 1998b, 1998c) published checklists and annotated bibliographies of the turtles and crocodiles, lizards, and snakes of Sri Lanka. Comprehensive publications are available on snakes (de Silva 1980) and color guides were more recently published on snakes (de Silva 1990) and lizards (Somaweera and Somaweera 2009) of Sri Lanka.

The *2007 Red List of Threatened Fauna and Flora of Sri Lanka* (IUCN Sri Lanka and MoENR 2007) lists a total of 171 reptile species where 101 (59%) are endemic (Fig. 3), with more being added (e.g., Gower et al. 2011; Maduwage et al. 2009).

The herpetofauna of Sri Lanka—A short summary of the evolution of our knowledge base

Although our knowledge of Sri Lankan herpetofauna has considerably improved, new species still await discovery. This applies particularly to amphibians where traditional morphological approaches have fallen short of adequately describing species diversity (for comparison see Oliver et al. 2009; Stuart et al. 2006; Vieites et al. 2009). Modern genetic analyses have shown a much higher species diversity than previously expected (overview in Pethiyagoda et al. 2006). In addition, new species of reptiles have been discovered during the last years of intensified field work in Sri Lanka. This includes "seemingly" better known agamid genera such as *Calotes*, *Ceratophora*, *Cophotis*, and *Otocryptis* (for an overview, see references in Bahir and Surasinghe 2005 and Somaweera and Somaweera 2009; Fig. 4). In addition, new species of scincid and gekkonid lizards and snakes were recently

Figure 3. Male specimen of *Lyriocephalus scutatus*, the most charismatic lizard of Sri Lanka. The genus is monotypic and endemic to Sri Lanka. *Photo by Walter R. Erdelen.*

described (overviews in de Silva 2006; Somaweera and Somaweera 2009).

As already indicated by Pethiyagoda et al. (2006), despite recent work on taxonomy and systematics comparatively little is known about the biology of Sri Lankan amphibians. Basic ecological information at both the population and species levels is unavailable for most, if not all taxa. Additionally, geographic distribution patterns and their dynamics are poorly understood or not known at all. The rarity of amphibian species, their patchy distribution, and possibly highly fragmented or small populations have neither been adequately recorded nor monitored over time, especially in view of human-induced habitat or microhabitat changes. Similarly, we lack this information for most Sri Lankan reptile species as well. An exception may be studies on the genus *Calotes* including analyses of geographic distribution patterns, intraspecific variability, and population dynamics (Erdelen 1977, 1983, 1984, 1988a; for a more recent study of *C. nigrilabris* see Amarasinghe et al. 2011).

Our knowledge of amphibian and reptile diversity in Sri Lanka has profoundly improved during recent times (within the last decade). This improvement has been the result of a "new age of herpetology, characterized both by increased international cooperation in research and by the blossoming of herpetology as a research discipline for many young Sri Lankan zoologists" (de Silva 2006). This process was influenced or catalyzed by major herpetological events held in Sri Lanka, including the 1996 International Conference on the Biology and Conservation of the Amphibians and Reptiles of South Asia, held at the University of Peradeniya (de Silva 1998), and the 4^{th} World Congress of Herpetology, held at Bentota, Sri Lanka in 2001 (see Dodd and Bartholomew 2002).

Conservation issues

General observations

Sri Lanka has a long tradition of preserving its wildlife. It was one of the earliest countries to set aside areas for wildlife protection and take conservation measures for its plant and animal life. Ideas of preserving nature in Sri Lanka may date back to the advent of Buddhism, about 2,500 YBP. Sanctuaries were already established in Sri Lanka in the 12^{th} century, possibly earlier (see Crusz 1973; DeAlwis 1969; Erdelen 1988b; Ministry of Forestry and Environment 1999).

Currently, Sri Lanka has over 500 protected areas including over 90 key biodiversity areas recently identified jointly by the Wildlife Heritage Trust and the University of Peradeniya. Sri Lanka's protected areas—covering about 18% of the island's total land area—are principally

Figure 4. Range restricted endemic forest lizards. Top left: *Ceratophora tennentii*, male; top right: *Cophotis ceylanica*, male; bottom left: *Calotes liocephalus*, juvenile; bottom right: a newly discovered endemic but widespread species of scincid lizard (*Eutropis tammanna*; described by Das et al. 2008). *Eutropis tammanna photo by Indraneil Das; all others by Walter R. Erdelen.*


Figure 5. Two species of reptiles endemic to the Knuckles range, the gekkonid *Cyrtodactylus soba* (left) and the scincid *Nessia bipes* (right). *Photos by Indraneil Das.*

managed by the Forest Department and the Department of Wildlife Conservation (for details see Dela 2009). The most recent significant international achievement has been the recognition of the Central Highlands of Sri Lanka, including the Peak Wilderness Protected Area, the Horton Plains National Park, and the Knuckles Conservation Forest (see Fig. 5), as a World Heritage Site.

As stated in the relevant text of the World Heritage Committee (34 COM8B.9) decision: "the property includes the largest and least disturbed remaining areas of the submontane and montane rain forests of Sri Lanka, which are a global conservation priority on many accounts. They include areas of Sri Lankan montane rain forests considered as a super-hotspot within the Western Ghats and Sri Lanka biodiversity hotspot. More than half of Sri Lanka's endemic vertebrates, half of the country's endemic flowering plants and more than 34% of its endemic trees, shrubs, and herbs are restricted to these diverse montane rain forests and adjoining grassland areas." In the same text it is further noted that: "Of the 408 species of vertebrates, 83% of indigenous fresh water fishes and 81% of the amphibians in Peak Wilderness Protected Area are endemic, 91% of the amphibians and 89% of the reptiles in Horton Plains are endemic, and 64% of the amphibians and 51% of the reptiles in the Knuckles Conservation Forest are endemic."

As indicated above, conservation efforts in Sri Lanka previously focused largely on charismatic and well-known species such as the larger mammal and bird species and endemic plant and animal species. Amphibians and reptiles have largely been ignored, a situation similar to other Asian countries such as Indonesia (Iskandar and Erdelen 2006). This fact underscores the importance of specific mention of amphibians and reptiles in the nomination of this new World Heritage Site, which is of outstanding importance to the long-term conservation of a significant segment of Sri Lanka's herpetofauna and its fauna and flora in general.

Sri Lanka's fourth country report to the Convention of Biological Diversity lists the following major threats to Sri Lanka's biodiversity: (1) habitat loss and fragmentation, in particular regarding wet zone ecosystems; (2) habitat degradation; (3) overexploitation of biological resources; (4) loss of traditional crop and livestock varieties and breeds; (5) pollution; (6) human-wildlife conflicts; (7) spread of alien invasive species; and (8) increasing human population density (Dela 2009). Without doubt numbers one and two above are the most important direct threats to the herpetofauna of Sri Lanka, particularly in regards to endemic species. Pesticide use and air pollution possibly affect amphibian populations more drastically than reptiles, due to their complex life histories (Ariyasiri et al. 2011). The long-term viability of amphibian populations critically depends on the state of both the aquatic ecosystems they use during their "bimodal" life cycle and the associated terrestrial ecosystems they inhabit (see Becker et al. 2007).

As pointed out by Pethiyagoda et al. (2006), the area of greatest concern for amphibians is the southwestern region of Sri Lanka where over 95% of forest cover has been lost and amphibian species are restricted in their geographic distribution. The wet zone of Sri Lanka currently comprises well over 100 forest fragments, and areas where continuous forest exists from lowlands to higher elevations are rare. This situation is further aggravated by high human population density in the southwestern region of Sri Lanka with over 500 individuals/ km^2 (Dela 2009; see above).

Ecoregions and hotspots of biodiversity—The case of Sri Lanka

In their paper "Global 200," Olson and Dinerstein (1998) identified the 200 biologically most valuable ecoregions. The terrestrial ecoregions are defined as relatively large units of land containing a distinct assemblage of natural communities and species, with boundaries that approximate the original extent of natural communities prior to major land-use change (Olson et al. 2001). Biological distinctiveness was measured in terms of species richness, endemism, taxonomic uniqueness, unusual eco-

logical or evolutionary phenomena, and global rarity of habitat types (for details see Olson and Dinerstein 1998). This included the moist forests of the Western Ghats and Sri Lanka—both classified as Critical or Endangered as their conservation status. A more detailed analysis was presented in the Indo-Pacific terrestrial ecoregions conservation assessment (Wikramanayake et al. 2002). This assessment provided a detailed subdivision of the Western Ghats and also distinguished three ecoregions within Sri Lanka: (1) lowland rain forests, (2) montane rain forests, and (3) evergreen forests of the dry zone. The first two were considered globally outstanding with a conservation status of "critical" and given the highest assessment of need for effective biodiversity conservation - "class I" (see Fig. 6). The third was classified as regionally outstanding, vulnerable, and assigned "class II" as its conservation assessment (for details, see Wikramanyake et al. 2002).

In parallel, the assignment of global conservation priorities was based on the concept of "biodiversity hotspot," a term coined by Myers in the late 1980s (Myers 1988, 1990). The term originally referred to areas where "exceptional concentrations of endemic species are undergoing exceptional loss of habitat" (Myers et al. 2000). Other definitions include parameters like species richness, degree of endemism, numbers of rare or threatened species, and intensity of threat (see Reid 1998). One persistent discordant issue is that rare species may not occur in the most species-rich areas (e.g., Prendergast et al. 1993; see also Reid 1998; for vascular plant diversity and hotspots see discussions in Küper et al. 2004; Mutke and Barthlott 2005; Mutke et al. 2011).

Early work described the Western Ghats and Sri Lanka as a single unit in the list of global biodiversity hotspots (e.g., in Myers 1990). Based on the following factors: endemic plant species, endemic vertebrates, the occurrence of endemic plant and vertebrate species per 100 km^2, and the percentage of remaining primary vegetation, Myers et al. (2000) identified the "eight hottest hotspots" and included the Western Ghats and Sri Lanka.

The relationship between the hotspot and ecoregion approaches is not further discussed here (see e.g., Ladle and Whittaker (2011) for discussions of the two approaches) but a short comment on their interrelationships is of benefit. Regarding scale, the ecoregional approach generally is more fine-scale in nature. For instance, the Western Ghats and Sri Lanka comprise eight different ecoregions. In general, there is over 90% congruence between biodiversity hotspots and the global 200 ecoregions (for more details see Wikramanayake et al. 2002).

Statements outlined above show evidence of a highly unique and diverse herpetofauna in Sri Lanka. During the last decade Sri Lanka has become recognized as an amphibian hotspot of high global significance (Meegaskumbura et al. 2002; Pethiyagoda and Manamendra-Arachchi 1998) and a mega-hotspot of reptile diversity

Figure 6. Lowland rain forest at Sinharaja (top) and montane forest in the Knuckles Range (bottom; cardamom factory in the foreground). *Photos by Walter R. Erdelen.*

(Somaweera and Somaweera 2009). This recognition may be seen as a bottom-up approach, i.e. a taxon-specific approach to the issue of prioritizing biodiversity conservation, as used in the IUCN lists of threatened fauna and flora (see below). It may be seen as an indicator or a reaction to the fact that overall species and ecosystem conservation have been biased towards certain taxa (see above).

The consequence may be use of taxon-specific approaches to ensure specific characteristics in overall long-term conservation of species or species analyzed

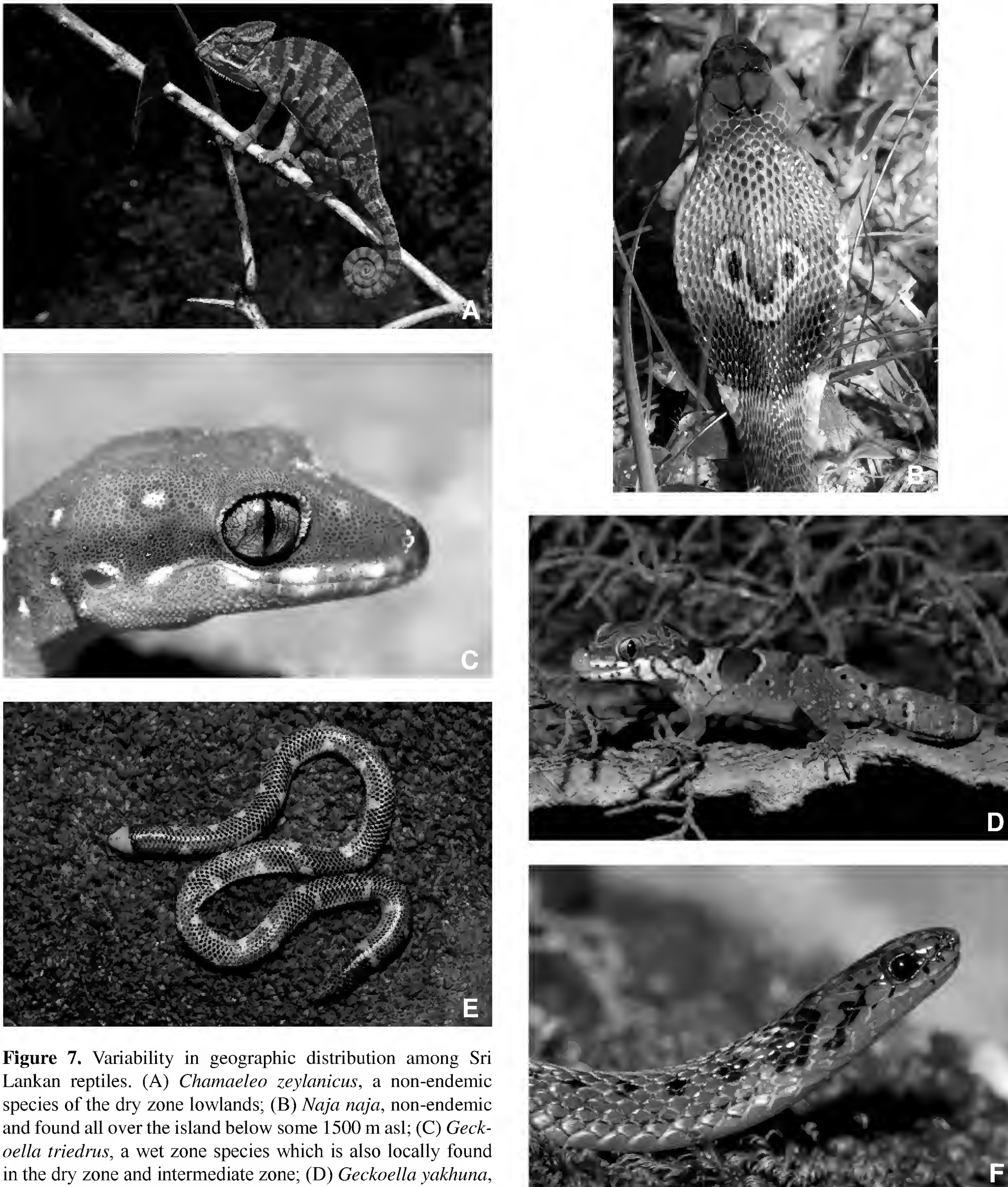

Figure 7. Variability in geographic distribution among Sri Lankan reptiles. (A) *Chamaeleo zeylanicus*, a non-endemic species of the dry zone lowlands; (B) *Naja naja*, non-endemic and found all over the island below some 1500 m asl; (C) *Geckoella triedrus*, a wet zone species which is also locally found in the dry zone and intermediate zone; (D) *Geckoella yakhuna*, restricted to the dry zone lowlands of the north; both species are endemic to Sri Lanka and need further study as regards to intraspecific variation. The status of the third species occurring in Sri Lanka (*G. collegalensis*) is unclear (Somaweera and Somaweera 2009); (E) *Rhinophis homolepis*, an endemic uropeltid snake found in the wet zone lowlands; fossorial amphibians and reptiles may be environmental indicators and key groups for an understanding of species evolution in Sri Lanka (see Gans 1993); (F) *Haplocercus ceylonensis*, an endemic colubrid snake found in the wet zone highlands. *Photos by Indraneil Das.*

(for examples of variation in status and distribution of species see Figs. 1 and 7). This approach may lead to a new insight regarding conservation aspects specific to the herpetofauna of Sri Lanka and be vital for overall or "holistic" conservation of biodiversity. Concretely, this approach may relate to rarity, small population sizes, and patchy geographic distribution of many of Sri Lanka's amphibian species.

IUCN Lists

The 2007 IUCN red list of threatened fauna and flora of Sri Lanka lists 33% of all vertebrates as nationally threatened (63% endemic to Sri Lanka). Among major groups of vertebrates reptiles and amphibians rank first in numbers of threatened species, followed by bird, mammal, and freshwater fish species (IUCN Sri Lanka and MoENR 2007).

The 2009 *IUCN State of Amphibians of Sri Lanka*, based on a total species number of 105, draws a particularly bleak picture of endangerment: 20% are reported Extinct, 10% Critically Endangered, 34% Endangered, 6% Vulnerable, and 5% Near-threatened. Only 23% are of least concern and for 2% insufficient data are available to assess their status. Sri Lanka ranks highest among Asian countries, having the greatest percentage of threatened amphibians. It has lost some 20% of its amphibian species during the last century, and over 50% of the remaining species are prone to extinction (*IUCN State of Amphibians of Sri Lanka*, update of 7 April 2009, accessed through www.iucn.org).

Sri Lanka therefore is not only characterized by the highest degree of endemism among amphibians in Asia but also by the highest number of extinct amphibian species reported for an individual country. The loss of 20% of its amphibian species has been a result of human impacts on natural ecosystems during the last 100 years, particularly to natural forest ecosystems of the wet zone and central hills of Sri Lanka. It should be noted, however, that the meaning of "extinct" in this context is not based on absolute proof but on the lack of more recent species records.

One hundred and seventy-one indigenous reptile species, excluding marine species, were assessed by IUCN (2007). Of these, 16 (9.3%) species are considered Critically Endangered, 23 (13.5%) Endangered, and 17 (10%) Vulnerable. This translates into a total of 56 (32.7%) species with their existence threatened. Of these, 37 (66%) are species endemic to Sri Lanka.

In the 2007 IUCN list, concern is expressed *inter alia* about the facts that: (1) national red lists have not been integrated into national policies or other ongoing national conservation actions; (2) better awareness of the contents of these lists needs to be created among relevant line ministries; and (3) the status of most threatened species has remained unchanged or worsened with time. These concerns need to be seriously addressed and jointly translated into concrete action by decision makers, the scientific community, and the public at large.

Institutional arrangement in Sri Lanka

Although this paper focuses on specific issues related to the conservation of amphibians and reptiles in Sri Lanka, this newer comprehensive understanding presented needs to be made relevant and tangible within the overall setup of institutions and agencies managing the environment, biodiversity, and sustainable development of the country. The key ministry mandated with sustainable development and environmental management in Sri Lanka is the Ministry of Natural Resources and Environment (MoENR). MoENR's regulatory commission is to monitor, revise, and report progress of the Environmental Action Plan and to formulate national policies for environmental protection and management. MoENR houses the National Biodiversity Secretariat who is responsible for policies and plans for national biodiversity conservation and attends to national implementation of the Convention on Biological Diversity (CBD) and the Cartagena Protocol (see Dela 2009 for further details). The main sectoral institutions within the MoENR are the Forest Department, the Department of Wildlife Conservation, the Central Environmental Authority, and the Marine Environment Protection Authority. An overview of national stake holders for implementing the CBD and the National Biodiversity Conservation Action Plan (BCAP)—main legislation relating to environmental conservation and management—and key state agencies outside the environmental sector dealing with biodiversity conservation in Sri Lanka are listed in Dela (2009).

De Silva (2001) compiled a list of government departments and organizations which have more specifically contributed to Sri Lankan herpetology. He lists some major non-governmental organizations (NGOs) who specially contribute to improving our knowledge of amphibians and reptiles in Sri Lanka. These NGOs are listed in alphabetic order below (from de Silva 2001; founding dates are given in brackets where available):

- Amphibia and Reptile Research Organization of Sri Lanka (ARROS).
- Conservation Breeding Specialist Group (IUCN/CBSG/SSC), Sri Lanka Network.
- Declining Amphibian Population Task Force, Working Group Sri Lanka (1999).
- March for Conservation.
- The Neo Synthesis Research Centre.
- The Royal Asiatic Society of Sri Lanka (1845).
- Snakebite Expert Committee, Sri Lanka Medical Association (1983).
- Turtle Conservation Project.
- The Wildlife and Nature Protection Society of Sri Lanka (1894).
- The Wildlife Heritage Trust of Sri Lanka (1990)
- The Young Zoologists Association (1972)

These institutions and agencies have enormous potential for enhancing efforts to jointly contribute to mainstreaming biodiversity conservation into cross-sectoral strategies and plans. This potential applies in particular to the development aspects and, therefore, for the sustainable development of Sri Lanka in general. Better cooperation and planning among conservation stake holders in Sri Lanka would greatly increase conservation efforts and are essential in saving the largest portion of biodiversity in Sri Lanka.

Conservation of Sri Lanka's herpetofauna—A proposal

Knowledge of amphibian and reptile geographic distribution in Sri Lanka, especially endemic species, highlights the close association between their geographic distribution patterns and natural ecosystems. For most species we lack precise information about how species distributions are linked to specific habitats or microhabitats. This applies in particular to amphibians which show highly patched distributions and fragmented or small populations. Further studies are needed to determine if this is a result of "natural" patchiness, habitat fragmentation, or sampling artifact (see Janzen and Bopage 2011 for a forest patch herpetofauna study at approximately 1000 m asl).

Studies on extinction risks and population vulnerability have not been carried out for most species. Ecological and biogeographical studies are lagging far behind taxonomic and systematic studies. Without doubt, ecological and biogeographical studies should be continued and should parallel population studies (including monitoring of population dynamics), especially in view of severe habitat fragmentation and additional negative impacts expected to result from climate change.

All these efforts toward a better understanding of the status and endangerment of Sri Lanka's amphibians and reptiles need not only be sustained but considerably increased. This will require increased support and effort at national and international levels and must be embedded in the overall resolve for reinforcing biodiversity conservation in Sri Lanka.

Toward an Action Plan

Many important proposals have been made for the conservation of Sri Lanka's biodiversity and its herpetofauna (e.g., Das 1996b; de Silva 2006; IUCN Sri Lanka and MoENR 2007; Pethyiagoda et al. 2006). These are not repeated here, but an integrated action plan is proposed below which focuses on several areas of prime importance.

1) Mapping existing schemes of cooperation, identifying shortcomings, and providing an optimized scenario for partnership arrangements at national and international levels to make the best "use" of existing capacities.

2) Reinforcing scientific work on the amphibians and reptiles of Sri Lanka through a targeted approach and using all national capacities (governmental institutions and other entities, universities, NGOs, and other stake holders) and schemes of international cooperation. Scientific work should include a continuation of the highly successful taxonomic work of the past decade but should increasingly include ecological and biogeographical work to complement our knowledge of systematic relationships among taxa (for some recent problems see Pethyiagoda 2004).

3) Linking this endeavor to work on ecosystem or plant community classification and conservation as carried out by Sri Lankan universities, particularly in regards to botanical research or work in the fields of plant ecology and plant biogeography.

4) Developing schemes and scientific programs supported by the latest space technologies for monitoring the status of ecosystems in Sri Lanka for habitat restoration and recreating continuous habitat or ecosystems (particularly in the wet zone and central hills). Replanting and reconnecting forest fragments through planting of indigenous species, as has been carried out for years by the Department of Botany at Peradeniya University (e.g., Ashton et al. 2001).

5) Fostering joint education, research, and degree work in these fields at universities in Sri Lanka. This may need to be coordinated among universities interested in inter-university cooperation. Such a plan could create better employment opportunities and promote qualified staff to work in conservation and sustainable development sectors.

6) Making biodiversity education more inclusive, encompassing all levels of the education system including formal and informal education and arrangements for life-long learning. In addition, biodiversity education should become part of a massive effort to champion education for sustainable development in the country, closely linked to public awareness programs, particularly as needed for the conservation of amphibians and reptiles.

7) The results of these works should be interconnected to conservation work carried out by the Sri Lank-

an government authorities, in particular the Forest Department, the Department of Wildlife Conservation, and the Biodiversity Secretariat.

8) Fostering the role and capacity of the National Museum in overall conservation efforts for Sri Lankan herpetofauna in a national and international context, and in particular through reinforcing and facilitating the museum's international collaboration and programs of work.

9) Reinforcing *in situ* and *ex situ* conservation efforts for amphibians and reptiles in Sri Lanka. The zoological gardens at Dehiwela and the establishment of a new facility such as a "Sri Lanka Aquarium" might generate the needed public attention for the conservation needs of Sri Lanka and its herpetofauna (see 6).

10) Extending existing activities and programs in national and international ecotourism programs to include amphibians and reptiles as specific examples for creating environmental awareness and the need for biodiversity conservation.

11) Closer liaison between all stake holders in joint conservation efforts regarding biodiversity hotspots of south India's Western Ghats and Sri Lanka. A model approach could be developed for preserving biodiversity in both hotspots (sometimes considered a single hotspot), serving as a template for similar analysis in other biodiversity hotspots. This needs to be based on a changed mind-set, with a paradigm shifted from "protection" to "conservation," which includes active, research-based management interventions (R. Pethiyagoda, pers. comm.).

For examining the feasibility of such an action plan or a similar initiative, a workshop or other "kick-off" meeting with all relevant governmental and non-governmental stake holders might be a useful first step. A proposed meeting may contribute to significant positive efforts in capacity and resource development (a multiple win situation for all stake holders) and for sustaining Sri Lanka's faunal and floral wealth for future generations.

Conclusions and outlook

Our knowledge of Sri Lanka's biodiversity has experienced a quantum leap during the last decade. This is underscored by massive efforts to scale up taxonomic research, in particular of the fauna of Sri Lanka, which has led to the discovery of a substantial number of new species among invertebrate and vertebrate taxa. Specifically, genetic studies have contributed to new insights into the country's biological diversity. The increase in numbers of amphibian species scientifically described has been outstanding, making it the vertebrate group with the highest percentage of endemic species (some 90%) in Sri Lanka; also more than twenty new reptile species have been described during the last decade.

Biodiversity efforts in Sri Lanka need to be further streamlined between all governmental and non-governmental institutions and agencies. This should include the consideration of global climate change as possibly the most important factor affecting the future of Sri Lanka's biodiversity, particularly the exceptional biodiversity in montane areas. A specific focus must be put on connectivity of natural habitat, particularly in the lowland wet zone and highlands where forests have been severely fragmented—a phenomenon making these ecosystems particularly prone to impacts of climate change and exacerbated by the large number of aggressive invasive alien species now found in the highlands of Sri Lanka (R. Pethyiagoda, pers. comm.).

The division of institutional activities and the enormous number of ongoing projects related to the conservation of Sri Lanka's biodiversity may need to be inventoried and mapped at both national and international levels in order to optimize future efforts. This is especially needed because of the limited human and financial resources available to address biodiversity issues in Sri Lanka. These efforts should be accompanied by the formation of an inter-institutional coordination plan for biodiversity research, monitoring, and identification of threats, as is already proposed in the *Fourth Country Report from Sri Lanka to the Convention on Biological Diversity* (see Dela 2009, Appendix III, p. vii). Such an initiative may benefit from a regional approach, exchanging experience and addressing common issues especially since Sri Lanka and the Western Ghats of southern India are one of the most important global biodiversity hotspots containing ecoregions of outstanding regional and global value.

The Decade on Biodiversity (2011-2020) and the implementation recommendations of the Nagoya COP 10 conference such as the new biodiversity strategy and the biodiversity targets might offer a unique platform for launching and sustaining the initiatives outlined here. This platform could facilitate the release of an updated National Biodiversity Strategy and Action Plan for Sri Lanka which might be cast as a living strategic document, closely linked to the country's efforts to implement sustainable development, with an increased focus on coping with the effects of global climate change and using the potential of a green economy.

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Range extension for *Duttaphrynus kotagamai* (Amphibia: Bufonidae) and a preliminary checklist of herpetofauna from the Uda Mäliboda Trail in Samanala Nature Reserve, Sri Lanka

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***Abstract.*—Uda Mäliboda Trail is an unstudied, remarkable forest located in the northwest region of Samanala Nature Reserve (SNR) in Sri Lanka's wet zone. Here we report the first record of *D. kotagamai* from Uda Mäliboda Trail and the lowest elevation records of four highland Rhacophorid frogs: *Pseudophilautus alto*, *P. asankai*, *P. femoralis*, and *Taruga eques*. Further, we present results of a preliminary study of herpetofaunal diversity in Uda Mäliboda Trail. Thirty-four amphibian (26 endemic and 19 Threatened) and 59 reptile (32 endemic and 19 Threatened) species were observed. This wet zone forest supports high herpetofaunal diversity; however activities such as deforestation, human encroachment, mining, agriculture, dumping, road construction, and a hydroelectric power station threaten the ecology of this biologically diverse forest.**

Key words. Amphibians, awareness, conservation, *Duttaphrynus*, global biodiversity hotspot, *Pseudophilautus*, reptiles, Sri Lanka, threatened, wet zone

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Introduction

Western Ghats and Sri Lanka have collectively been designated a global biodiversity hotspot (Mittermeier et al. 2004; Myers et al. 2000). Favorable environmental factors such as high rainfall, humidity, and a high density of undergrowth vegetation in this region have assisted in sustaining regional diversity and distinctness (Bossuyt et al. 2005; Gunawardene et al. 2007). Sri Lanka comprises the smaller portion of the hotspot, with a total land area of 65,610 km^2. Despite its small size, the region has a spectacular assemblage of amphibians and reptiles. Recent molecular studies on amphibians (Rhacophorids and Caecilians) and Uropeltid snakes have shown that Sri Lanka has maintained a fauna distinct from the Indian mainland (Bossuyt et al. 2004; Meegaskumbura et al. 2002; Pethiyagoda 2005), yet these subregions are separated only by about 300 kilometers (direct distance).

Of Sri Lanka's three major climatic zones (wet, intermediate, and dry) the wet zone harbors a significantly high level of herpetofaunal diversity and endemism (Bambaradeniya et al. 2003; Senanayake et al. 1977; Wijesinghe and Dayawansa 2002). The wet zone receives abundant rainfall (annual average 3,000 mm), has considerable forest cover, and maintains favorable humidity and temperatures to support such high herpetofaunal diversity. Previous studies have noted that some herpetofaunal species as well as the wet zone forests themselves are threatened due to a variety of human activities (e.g., IUCN-SL and MENR-SL 2007). Many wet zone forests have yet to be studied. Uda Mäliboda in the Kegalle district (Sabaragamuwa Province) is one such unstudied wet zone forest.

Kotagama's dwarf toad (*Duttaphrynus kotagamai*) is endemic and Endangered and is one of the rarest bufonids in Sri Lanka (De Silva 2009). Originally described from the Sinharaja World Heritage Site in 1994 by Prithiviraj Fernando and Nihal Dayawansa (Fernando et al. 1994) this toad is known only from the Kitulgala, Massena, Erathna, and Delwala forest areas (Dutta and Manamendra-Arachchi 1996; Goonatilake and Goonati-

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lake 2001). It favors a few primary lowland rain forests in the wet zone with elevations below 1,070 m (IUCN-SL 2011). According to Manamendra-Arachchi and Pethiyagoda (2006) the holophoront (USNM 311595 H) has been lost from the National Museum of Natural History, Washington, D.C. (USA). Herein we describe new localities and a range extension for *D. kotagamai* from a lowland rain forest in the northwestern boundary of the Samanala Nature Reserve (SNR) and further provide a preliminary checklist of herpetofauna from the Uda Mäliboda Forest area.

Materials and methods

We used visual encounter survey methods (Crump and Scott 1994) to conduct herpetofaunal surveys for a total of 17 days and nights between 2006 and 2011. Night searches were performed using headlamps and flashlights. We searched specific microhabitats including underneath stones and decaying logs, inside tree holes, and other potential herpetofaunal retreats. Road kills and data from animals dispatched by villagers were also used as sources of information. Specimens were hand captured, photographed, identified using field guides and scientific publications (Ashton et al. 1997; De Silva 2009; Dutta and Manamendra-Arachchi 1996; Maduwage et al 2009; Manamendra-Arachchi et al. 2007; Manamendra-Arachchi and Pethiyagoda 2006; Meegaskumbura et al. 2010; Somaweera 2006; Somaweera and Somaweera 2009; Vogel and Rooijen 2011; Wickramasinghe et al. 2007a, b), and then released back to the original capture site without injury. Species nomenclature was based on Frost et al. (2006), Kotaki et al. (2010), Sumida et al. (2007), and Senaratna (2001), and conservation status was evaluated on the IUCN-SL and MENR-SL (2007).

Study area and habitats

The Samanala Nature Reserve (SNR) is one of the largest and most important forest areas for endemic biodiversity in Sri Lanka and is owned by the Central Highlands World Heritage Centre (UNESCO 2011). The Study area lies between 6°53'01.58" N and 80°26'31.18" E with elevations ranging from 300-700 m (Fig. 1). This forest area is part of the Kegalle district in Sabaragamuwa Province. Average annual rainfall ranges from 3,000-4,500 mm and the average annual temperature is 27.9 °C (Fig. 2). The vegetation of Uda Mäliboda Trail is categorized as lowland wet evergreen forest (Gunatilleke and Gunatilleke 1990) and is comprised of the following dominant genera: *Doona*, *Stemonoporus*, *Calophyllum*, *Syzygium*, *Shorea*, *Dipterocarpus*, *Cullenia*, and *Mesua* (Table 1). Pilgrims use four main trails annually between December and April to reach Adams Peak to worship. The Uda Mäliboda Trail starts from the "Uda Mäliboda village" and continues through Madáhinna (Kuruwita trail) via Adams Peak (elevation 2,245 m). This is the longest trail and is seldom used by pilgrims since it consists of rough terrain and narrow foot paths (Karunarathna et al. 2011).

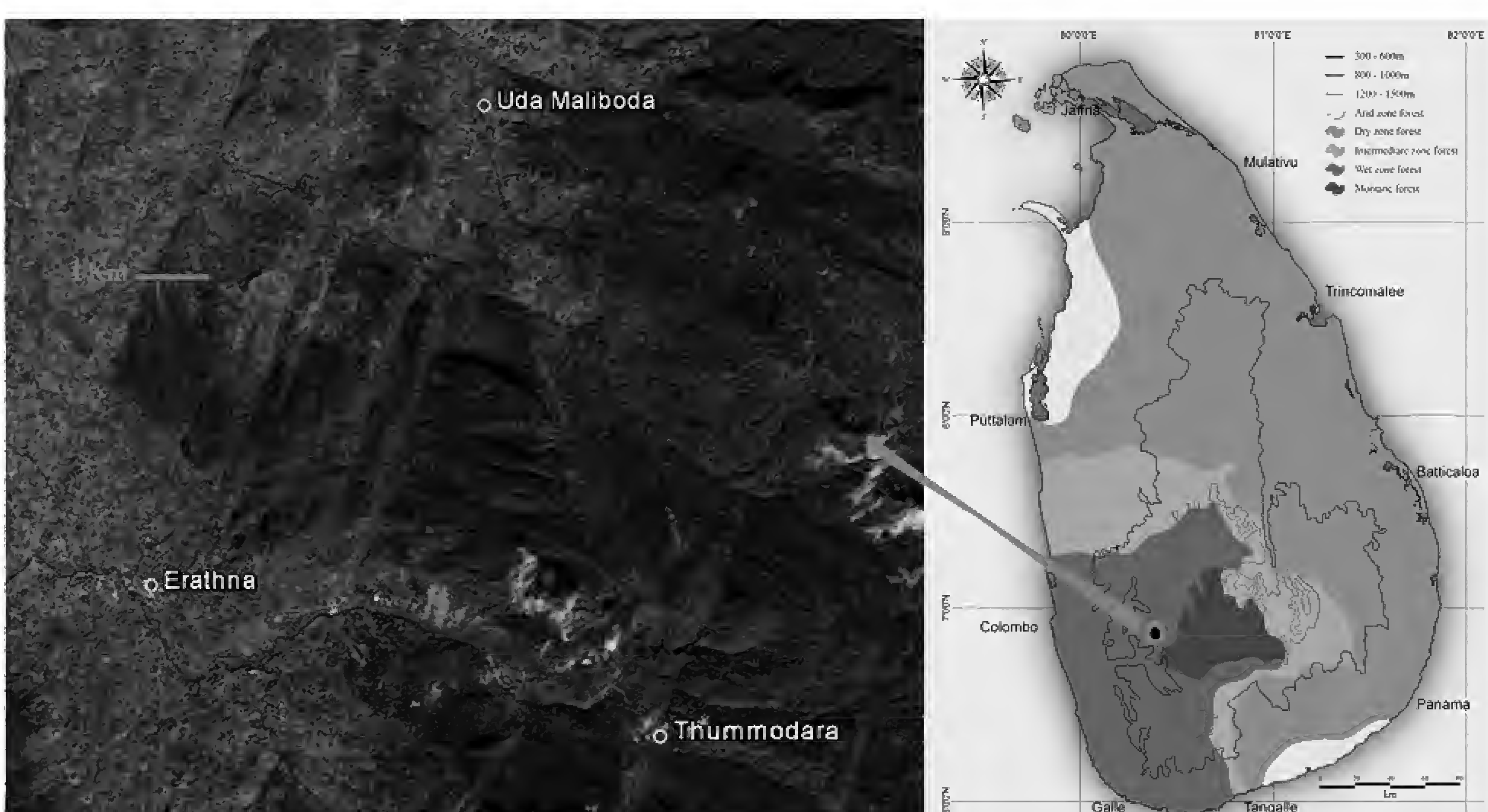


Figure 1. Map of study area (sky view source: Google map).

Table 1. Floral species presence in different level of Uda Mäliboda area (Uda Mäliboda Trail in SNR).

Prominent layer	Plant species diversity
Canopy	*Adinandra lasiopetala, Bhesa ceylanica, Calophyllum trapezifolium, Cullenia ceylanica, Shorea affinis, S. gardneri, Litsea gardneri, and Palaquium rubiginosum*
Subcanopy	*Apodytes dimidiata, Artocarpus nobilis, Calophyllum walkeri, Caryota urens, Cinnamomum ovalifolium, Cryptocarya wightiana, Dillenia triquetra, Elaeocarpus amoenus, Eugenia mabaeoides, Garcinia quaesita, Gordonia speciosa, Madhuca moonii, Mesua ferrea, Oncosperma fasciculatum, Schumacheria alnifolia, Stemonoporus gardneri, S. oblongifolia, Syzygium firmum, and S. turbinatum*
Climbers	*Calamus thwaitesii, Cosinium fenestratum, Cyclea peltata, Freycinetia walkeri, Rubus rugosus, and Smilax perfoliata*
Understory	*Acronychia pedunculata, Agrostistachys coriacea, Alpinia abundiflora, Amomum echinocarpum, Amomum masticatorium, Amorphophallus paeoniifolius, Arundina graminifolia, Calanthes* sp., *Cinnamomum verum, Clusia rosea, Cyathea crinita, Hedychium coronarium, Hortonia ovalifolia, Ipsea speciosa, Macaranga indica, Neolitsea cassia, Osbeckia aspera, Osbeckia lantana, Rhodomyrtus tomentosa, Strobilanthes* sp., *Syzygium cordifolium, Syzygium revolutum, and Utricularia striatula*

Results and discussion

New record for *D. kotagamai*

We report the occurrence of the Endangered, rare, and endemic *D. kotagamai* (Fernando and Dayawansa 1994) from Uda Mäliboda forest (Uda Mäliboda Trail) in the northwest region of the Samanala Nature Reserve (SNR = Peak Wilderness Sanctuary). According to Fernando et al. (1994), this species is distinguished from other *Duttaphrynus* species known from Sri Lanka and southern India by combination of the following characters: prominent parietal ridges on the head; long and narrow unlobulated parotoid glands; most areas of the anterior back are smooth; warts present on upper flank, supraorbital, and parietal ridges; tips of digits and tips of spinous warts black; first finger slightly longer than second finger (Fernando et al. 1994). Coloration in life is described as: orange-brown on dorsal surface mottled with dark brown (juveniles dorsal color is light golden); light cross band between eyes and distinct dark cross band on forearm, forefoot, tarsus, and tibia; less distinct cross band on upper arm and femur; lower jaw with alternate dark and light markings; ventral surface whitish mottled with dark brown, especially over sternum.

Eleven *D. kotagamai* were encountered during our survey. These toads were only found in primary forest and absent from human-disturbed areas. Except for one specimen, all were found within ~10 m of a small stream. (Fig. 3), and all but four individuals were observed at night. Three individuals from Uda Mäliboda measured: two males SVL 32.6 mm, 35.2 mm, and a female SVL 38.5 mm. We also found *D. kotagamai* in another previously unknown locality on an adjacent mountain in Deraniyagala in Kegalle district (Table 2). This mountain is located about five km north of Uda Mäliboda. There are no previous records of *D. kotagamai* from the Uda Mäliboda Trail (SNR; see De Silva 2009; Dutta and Manamendra-Arachchi 1996; IUCN-SL 2011; Manamendra-Arachchi and Pethiyagoda 2006; Goonatilake and Goonatilake 2001). The Uda Mäliboda locality is approximately six km (direct distance) from “Eratne” (Kuru river basin), the nearest published location. The direct distance between the onymotope and the new location is about 80 km. All of these areas have closed canopies with wet and cool habitats (Fig. 4).

Figure 2. View of forest in Uda Maliboda (larger water resource in the SNR).

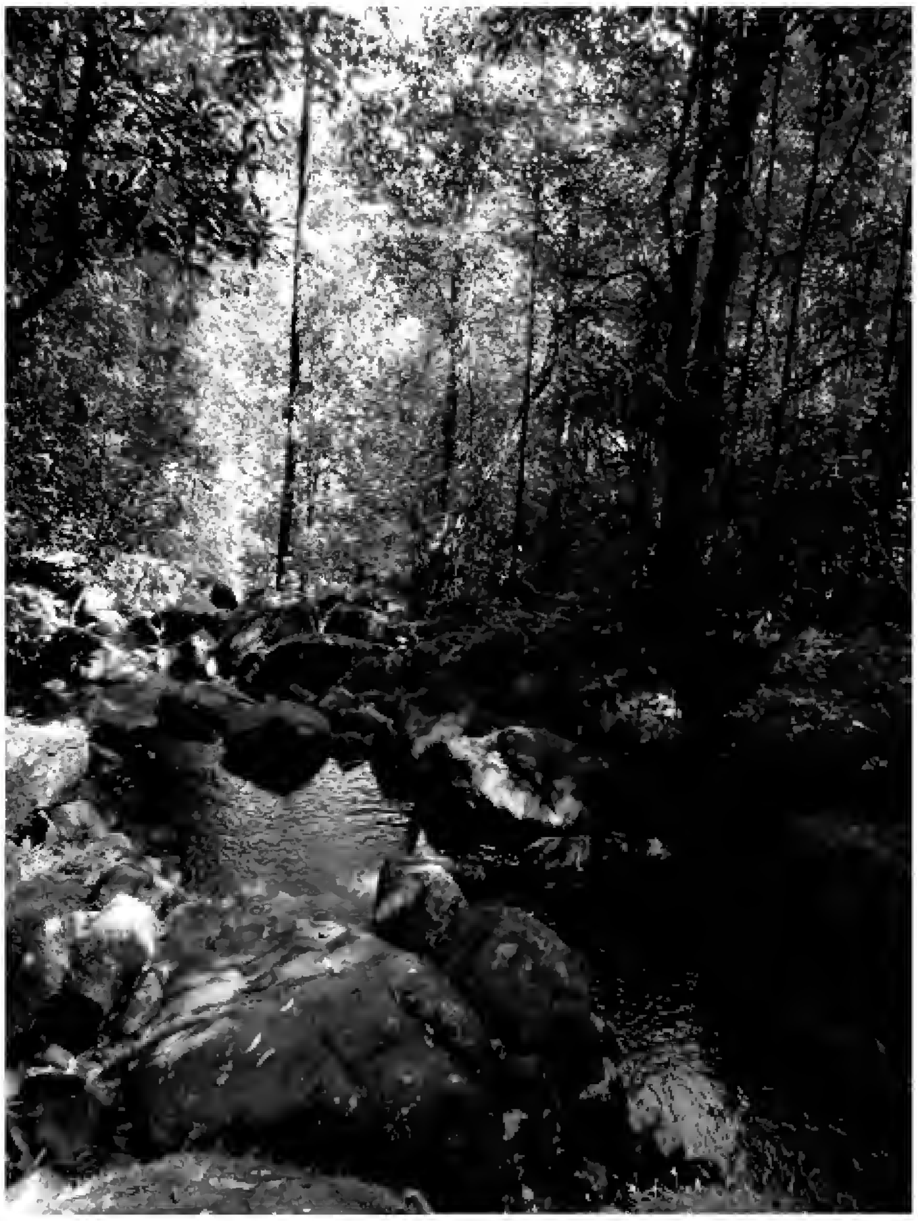


Figure 3. Cascade habitat: shrub mixed with riverine forest patch.

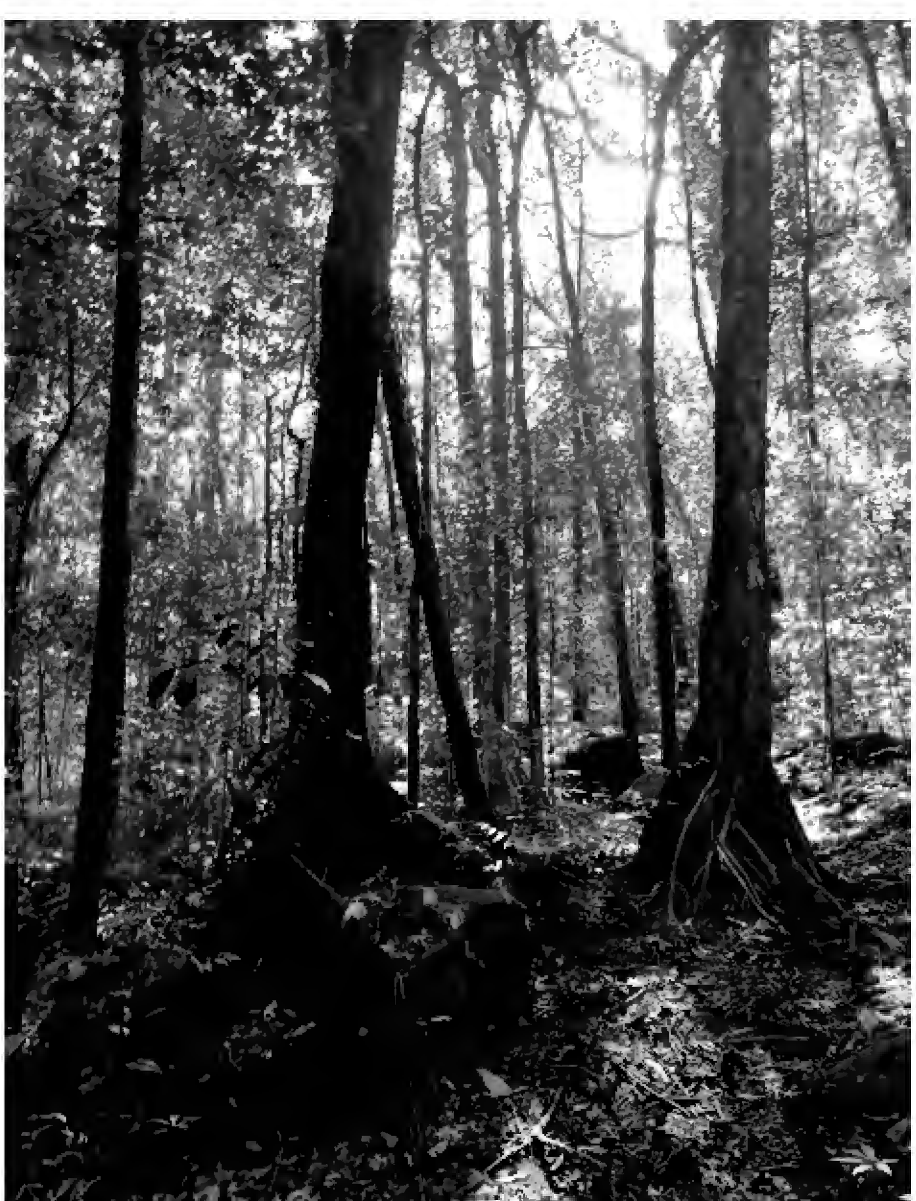


Figure 4. Inside forest: tall trees, mixed vegetation with good leaf litter.

Based on the infrequent calls heard during our survey periods this species is presumably rare in Uda Mäliboda. It is aggressive when handled and releases a low-pitched distress call "crick, crick, crick…". With two new locations and a subsequent range extension, we can trace the probable distribution of *D. kotagamai* prior to fragmentation. The new locations indicate a larger distribution than previously concluded. As a result of severe fragmentation and habitat degradation in the area, local extinctions of previous populations have likely occurred in the past with current populations known only from a few isolated primary forest patches.

Herpetofaunal diversity

During the study we encountered 34 amphibian species representing 15 genera and seven families (Table 3). Among those genera *Adenomus*, *Lankanectes*, *Nannophrys*, and *Taruga* are endemic to Sri Lanka. Our results show that at least 31% of Sri Lanka's extant amphibians occur in the Uda Mäliboda area (Fig. 5). Twenty-six of the 34 species encountered (76%) are endemic, five (14%) are considered Near Threatened, four (11%) are Vulnerable, and ten (29%) are classified as Endangered (IUCN-SL and MENR-SL 2007). Families with the greatest number of endemic species include Rhacophoridae (16 species) and Dicroglossidae (six species), while the family Ichthyophiidae, Ranidae (two species each) and Nyctibatrachidae (one species) show the lowest rates of endemism. When considering the 34 species by their primary mode of living, 15 (44.1%) were arboreal, 10 (29.4%) terrestrial, seven (20.6%) aquatic, and two (5.9%) fossorial species.

Most amphibian species observed after brief periods of rain since many species frequently use temporary pools created by these showers. Two large streams course forest acting as barriers that restrict some species to particular habitats. Among the most commonly encountered amphibians were *Pseudophilautus folicola*, found on low growing woody vegetation near water bodies under closed canopy, and *Fejervarya kirtisinghei*, occurred near water bodies lacking canopy. Four Endangered and endemic highland species: *P. alto* (1,890-2,135 m elevation), *P. asankai* (810-1,830 m), *P. femoralis* (1,600-2,135 m), and *Taruga eques* (1,750-2,300 m; Manamendra-Arachchi and Pethiyagoda 2006) were encountered at this study site, approximately 700 m elevation (lowest elevation ever recorded for these species).

We report a range extension for *Pseudophilautus sarasinorum*, an Endangered species previously known only from the following localities: Peradeniya (07°16' N, 80°37' E; Onymotope); Bogawanthalawa-Balangoda road (near 25th km post), elevation 1,300 m (06°45' N, 80°2' E); Corbett's Gap, elevation 1,000 m (07°22' N, 80°50' E); Hunnasgiriya, elevation 367 m (07°23' N, 80°41' E); Agra Arboretum, elevation 1,555 m (06°50'

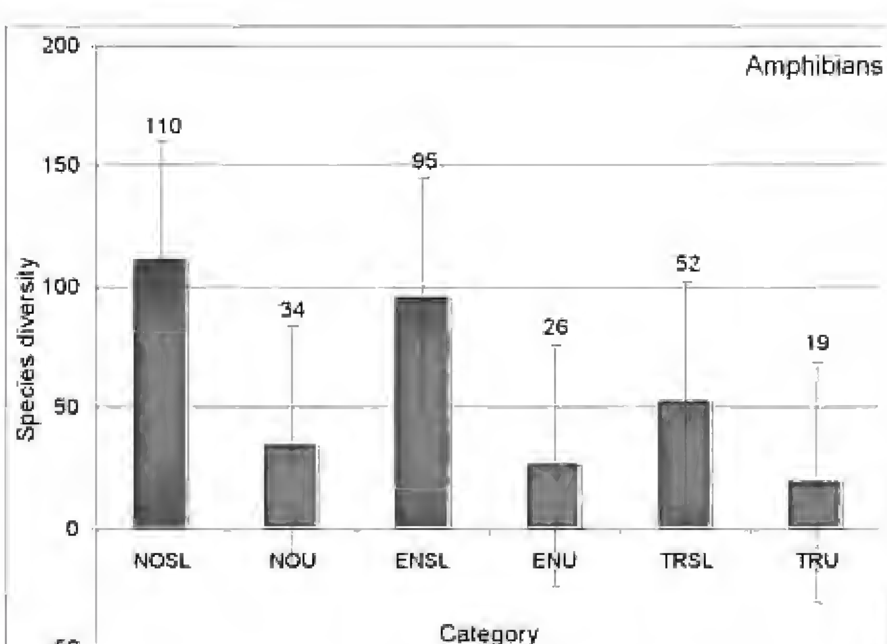
Table 2. Description of the 11 observed *D. kotagamai* individuals during the study period from Uda Mäliboda.

Date	Sex	Micro-habitat
18 January 2009	Male	Mid-stream boulder
	Male	Forest floor with leaf litter
	Female	Stream-bank boulder
17 April 2009	Female	Rock crevice
	Male	Stream-bank boulder
25 December 2009	Male	Stream-bank
07 May 2010	Male	Stream-bank
	Male	Stream-bank
22 August 2010	Female	Forest floor with leaf litter
	Male	On footpath
03 October 2011	Male	Stream-bank boulder

N, 80°40' E; Manamendra-Arachchi and Pethiyagoda 2005). Sumida et al. (2007) suggested the Sri Lankan population of *F. limnocharis* (in Dutta and Manamendra-Arachchi 1996; Manamendra-Arachchi and Pethiyagoda 2006) could be *F. syhadrensis*. However, recent molecular evidence revealed the Sri Lankan population of *F.* cf. *syhadrensis* is a separate and unnamed population belonging to a unique clade, together with *F. granosa* and *F. pierrei* (Kotaki et al. 2010). Therefore, we refrain from referring to the third *Fejervarya* species in Sri Lanka as *F. limnocharis* (in Dutta and Manamendra-Arachchi 1996; Manamendra-Arachchi and Pethiyagoda 2006) and instead refer it to as *F.* cf. *syhadrensis*.

Fifty-nine species of reptiles representing 37 genera from 11 families were recorded during these surveys (Table 4). Among those genera *Aspidura*, *Balanophis*, *Ceratophora*, *Cercaspis*, *Haplocercus*, *Lankascincus*, *Lyriocephalus*, and *Nessia* are considered endemic to Sri Lanka. Twenty-eight percent of Sri Lanka's extant reptiles were recorded in the study area (Fig. 5) including 28 species of lizards and 31 species of snakes. Of these 59 reptile species 32 (54%) are endemic, six (10%) Data Deficient, ten (17%) Near Threatened, five (8%) Vulnerable, and four (7%) Endangered (IUCN-SL and MENR-SL 2007). Families with the greatest species representation include Colubridae (17 species), Scincidae (11 species), and Gekkonidae (nine species), while the least represented family were Cylindrophidae, Pythonidae, and Typhlopidae (one species each). The highest number of endemic species were in the family Scincidae (nine species) and Colubridae (seven species), while the lowest number were in Cylindrophidae, Elapidae, and Typhlopidae (one species each). When considering the 59 species by primary mode of living: 24 (40.7%) were terrestrial, 21 (35.6%) arboreal, 11 (18.6%) fossorial, and three (5.1%) aquatic species.

Among the reptiles, *Otocryptis wiegmanni*, *Lankascincus greeri*, *Dendrelaphis schokari*, and *Hypnale zara* were the most commonly encountered species in and around footpaths. One unidentified species from the genus *Cyrtodactylus* was recorded during this survey and may be new to science. Several species of lizards (*Cnemaspis scalpensis*, *C. silvula*, *Hemiphyllodactylus typus*, *Eutropis beddomii*, and *Varanus bengalensis*) and snakes (*Boiga beddomei*, *Cercaspis carinatus*, *Haplocercus ceylonensis*, *Aspidura guentheri*, *Balanophis ceylonensis*, and *Typhlops mirus*) are noteworthy records. The Uda Mäliboda forest area also supports three highly venomous snakes: *Bungarus ceylonicus* (Sri Lanka krait), *Daboia russelii* (Russell's viper), and *Naja naja* (Indian cobra). Hence, both venomous and non-venomous snakes are frequently killed in this area due to fear and ignorance as a precautionary measure against snakebites. We failed to record any turtle species in the area, possibly due to low water temperatures in streams.



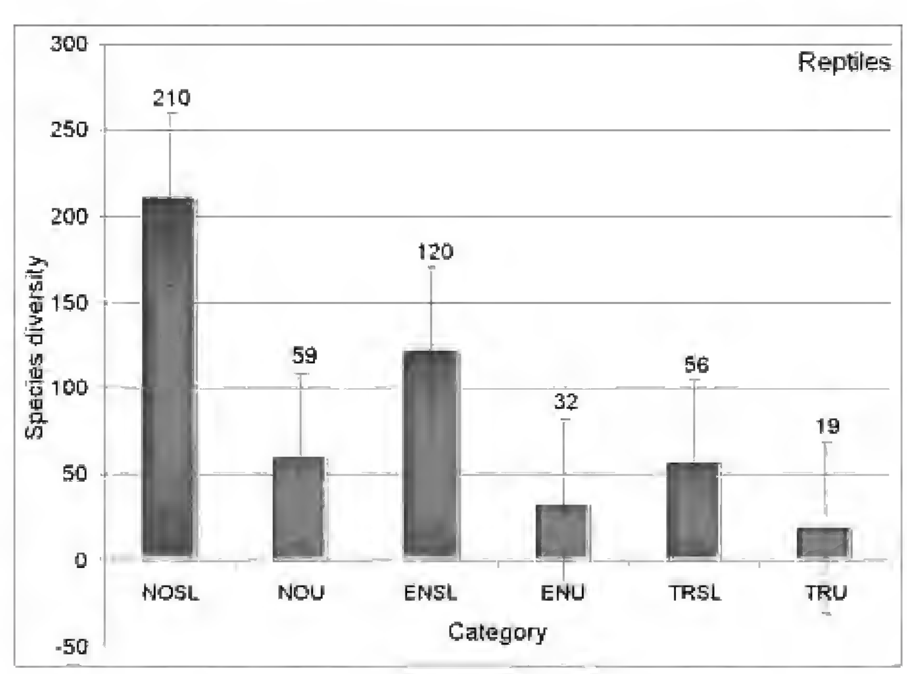


Figure 5. Comparison of amphibian (left) and reptile (right) diversity of Uda Mäliboda area with rest of the Sri Lankan species (Abbreviations: NOSL – total number of species in Sri Lanka; NOU – total number of species in Uda Mäliboda; ENSL – number of endemic species to Sri Lanka; ENU – number of endemic species in Uda Mäliboda; TRSL – number of threatened species in Sri Lanka and TRU – number of threatened species in Uda Mäliboda).

Table 3. Checklist of amphibian species in the Uda Mäliboda area (Abbreviations: E – endemic; EN – Endangered; VU – Vulnerable; NT – Near Threatened).

Family and species name	Common name
Bufonidae	
Adenomus kelaartii	Kelaart's dwarf toad [E]
Duttaphrynus kotagamai	Kotagama's dwarf toad [E, EN]
Duttaphrynus melanostictus	Common house toad
Microhylidae	
Kaloula taprobanica	Common bull frog
Microhyla rubra	Red narrow mouth frog
Ramanella nagaoi	Nagao's pugsnout frog [E, VU]
Ramanella obscura	Green-brown pugsnout frog [E, NT]
Nyctibatrachidae	
Lankanectes corrugatus	Corrugated water frog [E]
Dicroglossidae	
Euphlyctis cyanophlyctis	Skipper frog
Euphlyctis hexadactylus	Sixtoe green frog
Fejervarya kirtisinghei	Montain paddy field frog [E]
Fejervarya cf. *syhadrensis*	Common paddy field frog
Hoplobatrachus crassus	Jerdon's bull frog
Nannophrys ceylonensis	Sri Lanka rock frog [E, VU]
Rhacophoridae	
Pseudophilautus abundus	Labugagama shrub frog [E]
Pseudophilautus alto	Horton plains shrub frog [E, EN]
Pseudophilautus asankai	Asanka's shrub frog [E, EN]
Pseudophilautus cavirostris	Hollow snouted shrub frog [E, EN]
Pseudophilautus femoralis	Leafnesting shrub frog [E, EN]
Pseudophilautus folicola	Leaf dwelling shrub frog [E, EN]
Pseudophilautus hoipolloi	Anthropogenic shrub frog [E]
Pseudophilautus popularis	Common shrub frog [E]
Pseudophilautus reticulatus	Reticulated-thigh shrub frog [E, EN]
Pseudophilautus rus	Kandiyan shrub frog [E, NT]
Pseudophilautus sarasinorum	Muller's shrub frog [E, EN]
Pseudophilautus sordidus	Grubby shrub frog [E, NT]
Pseudophilautus stictomerus	Orange-canthal shrub frog [E, NT]
Polypedates cruciger	Common hour-glass tree frog [E]
Taruga eques	Mountain tree frog [E, EN]
Taruga longinasus	Long-snout tree frog [E, EN]
Ranidae	
Hylarana aurantiaca	Small wood frog [VU]
Hylarana temporalis	Common wood frog [E, NT]
Ichthyophiidae	
Ichthyophis glutinosus	Common yellow-band caecilian [E]
Ichthyophis pseudangularis	Lesser yellow-band caecilian [E, VU]

Threats and conservation

We believe the high diversity in wet zone forest habitats is due mainly to availability of abundant suitable microhabitat features (e.g., tree holes, caves, tree barks, rock boulders, crevices, water holes, decaying logs, loose soil, and other small niches) which create favorable environmental conditions for herpetofauna. According to our results, Uda Mäliboda area has a rich herpetofaunal diversity and endemism compared with other wet zone forests in Sri Lanka. A large number of people including tourists, devotees, and laborers annually visit Adams Peak via Uda Mäliboda Trail located within the SNR. As a result endemic and Threatened species, like many other fauna, are seriously affected by increasing pressure caused by habitat loss and degradation in montane forests, lower montane forests, and marshes. Major threats identified include illegal timber harvesting, illegal human encroachment, slash and burn forest clearing for human settlement and monoculture plantations (especially for tea cultivation), and gem mining. According to interviews with illegal timber harvesters, some rare tree species may be new to science are being harvested. Therefore, a further comprehensive study of flora is recommended.

Present human activities, the most severe being the construction of a hydroelectric power plant, continue to degrade and erode the remaining vestiges of this lush primary forest. Additionally, garbage (polythene) disposal along the Uda Mäliboda Trail by visitors and devotees is a threat that must be duly monitored by the Department of Wildlife Conservation (DWC) and the Forest Department (FD) of Sri Lanka. The Young Zoologists' Association (YZA) together with the Central Environmental Authority (CEA) has conducted annual polythene removal programs on other trail (Hatton) of SNR for the past 10 years. This has prompted other Government institutions and non-governmental organizations to engage in similar activities. We recommend that such programs be initiated on this trail in order to prevent further degradation of this lush forest.

Some human-altered landscapes such as tea plantations and *Pinus*, *Eucalyptus*, *Cyprus*, and *Casuarina* forest plantations are located in the foothills of the SNR. Most of these altered landscapes can be found up to about 800 m in elevation. There is an ongoing hydroelectric power plant development project in the study area (Fig. 6) and increased road traffic further threatens the area's fauna. Since a considerable area of the forest is altered by human activity, herpetofauna face increased threats because, in general, they are often highly sensitive to even slight environmental changes (e.g., McCallum 2007; Pough et al. 2004; Spellerberg 1991). Thus, the identification and designation of forest reserves on the perimeter of the SNR could function as suitable buffer zones. Additionally, public awareness programs are needed to help guide local people and policy makers de-

Table 4. Checklist of reptile species in Uda Mäliboda area (Abbreviations: E – endemic; EN – Endangered; VU – Vulnerable; NT – Near Threatened; DD – Data Deficient.

Family and species name	Common name
Agamidae	
Calotes calotes	Green garden lizard
Calotes liolepis	Whistling lizard [E, VU]
Calotes versicolor	Common garden lizard
Ceratophora aspera	Rough horn lizard [E, EN]
Lyriocephalus scutatus	Lyre-head lizard [E, NT]
Otocryptis wiegmanni	Sri Lankan kangaroo lizard [E, NT]
Gekkonidae	
Cnemaspis scalpensis	Gannoruva day gecko [E, DD]
Cnemaspis silvula	Forest day gecko [E]
Cyrtodactylus cf. *subsolanus*	Forest gecko sp.
Geckoella triedrus	Spotted bowfinger gecko [E, NT]
Gehyra mutilata	Four-claw gecko
Hemiphyllodactylus typus	Slender gecko [EN]
Hemidactylus depressus	Kandyan gecko [E]
Hemidactylus frenatus	Common house gecko
Hemidactylus parvimaculatus	Spotted house gecko
Scincidae	
Eutropis beddomii	Beddome's stripe skink [E, EN]
Eutropis carinata	Common skink
Eutropis macularia	Bronzegreen little skink
Eutropis madaraszi	Spotted skink [E, NT]
Lankascincus dorsicatenatus	Catenated lankaskink [E]
Lankascincus fallax	Common lankaskink [E]
Lankascincus gansi	Gans's lankaskink [E, NT]
Lankascincus greeri	Greer's lankaskink [E]
Lankascincus munindradasai	Munidradasa's lankaskink [E, DD]
Lankascincus sripadensis	Peakwilderness lankaskink [E, DD]
Nessia burtonii	Three toed snakeskink [E, EN]
Varanidae	
Varanus bengalensis	Land monitor
Varanus salvator	Water monitor
Pythonidae	
Python molurus	Indian python
Cylindrophidae	
Cylindrophis maculatus	Sri Lanka pipe snake [E, NT]
Colubridae	
Ahaetulla nasuta	Green vine snake
Ahaetulla pulverulenta	Brown vine snake [NT]
Boiga barnesii	Barnes's cat snake [E, NT]
Boiga beddomei	Beddoms cat snake [DD]
Boiga ceylonensis	Sri Lanka cat snake [VU]
Cercaspis carinatus	Sri Lanka wolf snake [E, VU]
Coeloganthus helena	Trinket snake
Dendrelaphis bifrenalis	Boulenger's bronze back [E]
Dendrelaphis caudolineolatus	Gunther's bronze back
Colubridae (cont.)	
Dendrelaphis schokari	Common bronze back [E]
Haplocercus ceylonensis	Black spine snake [E, DD]
Lycodon aulicus	Common wolf snake
Lycodon striatus	Shaw's wolf snake
Oligodon calamarius	Templeton's kukri snake [E, VU]
Oligodon sublineatus	Dumerul's kuki snake [E]
Ptyas mucosa	Rat snake
Sibynophis subpunctatus	Jerdon's polyodent
Natricidae	
Amphiesma stolatum	Buff striped keelback
Aspidura guentheri	Ferguson's roughside [E, NT]
Balanophis ceylonensis	Sri Lanka keelback [E, VU]
Atretium schistosum	Olive keelback
Xenochrophis asperrimus	Checkered keelback [E]
Typhlopidae	
Typhlops mirus	Jan's blind snake [E, DD]
Elapidae	
Bungarus ceylonicus	Sri Lanka krait [E, NT]
Naja naja	Indian cobra
Viperidae	
Daboia russelii	Russell's viper
Hypnale hypnale	Merrem's hump nose viper
Hypnale zara	Zara's hump-nosed viper [E]
Trimeresurus trigonocephalus	Green pit viper [E]

velop agendas that consider the importance of herpetofauna in maintaining a balanced and healthy ecosystem.

There is no doubt that SNR provides habitat for a high number of amphibian and reptiles species (many endemic and Threatened). We affirm that it is one of the most important herpetofaunal diversity areas in Sri Lanka, especially when considering the future conservation of endemic and threatened herpetofauna. Sri Lanka is known as an important herpetofaunal global hotspot (Bossuyt et al. 2004; Gunawardene et al. 2007; Meegaskumbura et al. 2002; Pethiyagoda 2005) and harbors an unusually high number of endemic species. Therefore, scientists and policy makers are strongly encouraged to make efforts conducting further research on other faunal groups, vegetation, and the forest's ecosystem as a whole. Furthermore, preserving the valuable herpetofaunal resources of the Uda Mäliboda Trail is paramount to the conservation of global biological diversity.

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Figure 6. Hydroelectric power plant (note: concrete wall built across the steam and concrete particles dump into the steam).

runathilake, Nadeesh Gamage, Mahesh De Silva (YZA), Prof. Deepthi Yakandawala, Dr. Suranjan Fernando (University of Peradeniya), and other members of the Young Zoologists' Association of Sri Lanka (YZA) for various help with this study. Villagers in the Uda Mäliboda area are acknowledged for their cooperation, sharing their observations, and logistic support. Finally, we would like to give our special thanks to John Rudge, Daniel Fogell, Kanishka Ukuwela, and Craig Hassapakis (ARC) for reviewing the initial daft of the manuscript and making improvements.

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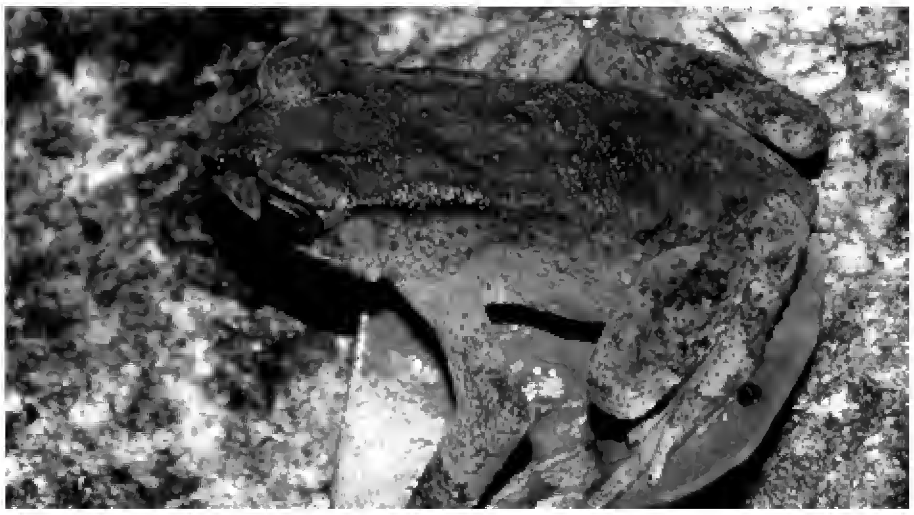

Figure 7. *Duttaphrynus kotagamai* (Male; Endangered).

Figure 8. *Lankanectes corrugatus* (relict).

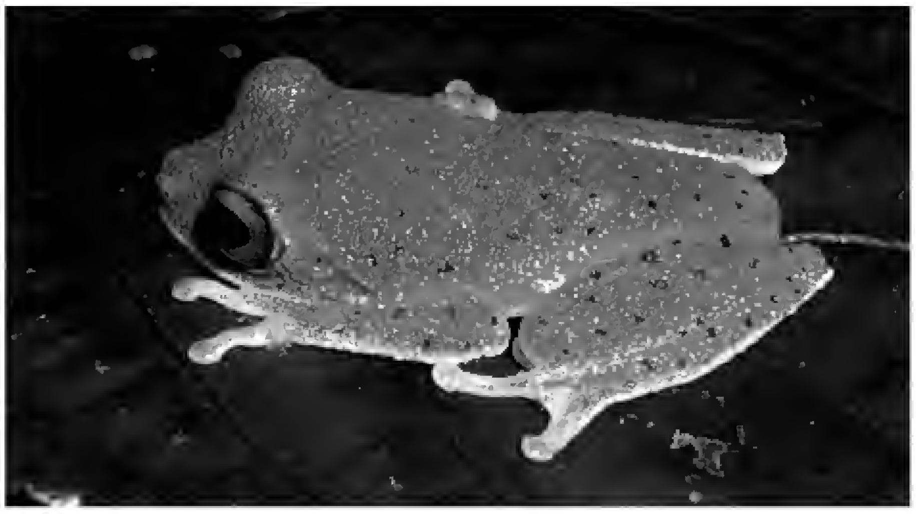

Figure 9. *Psedophilautus femoralis* (Endangered).

Figure 10. *Psedophilautus reticulates* (Endangered).

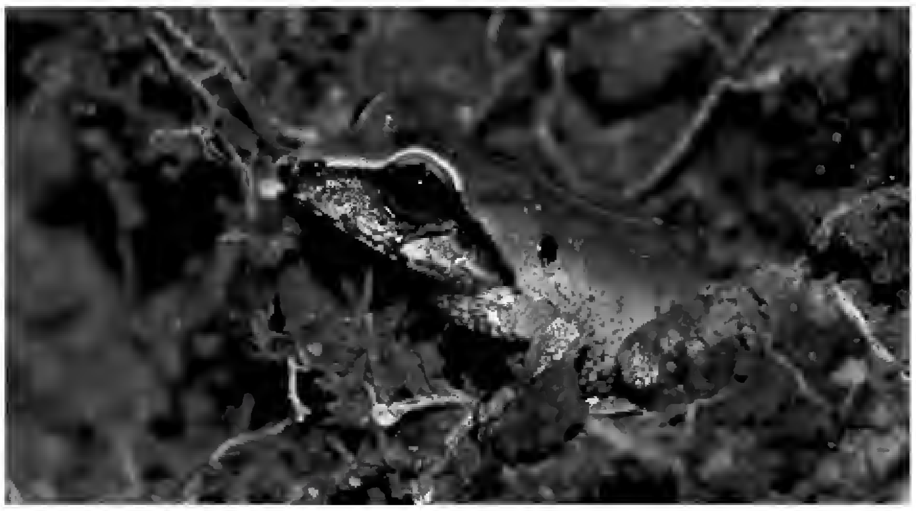

Figure 11. *Pseudophilautus alto* (Endangered).

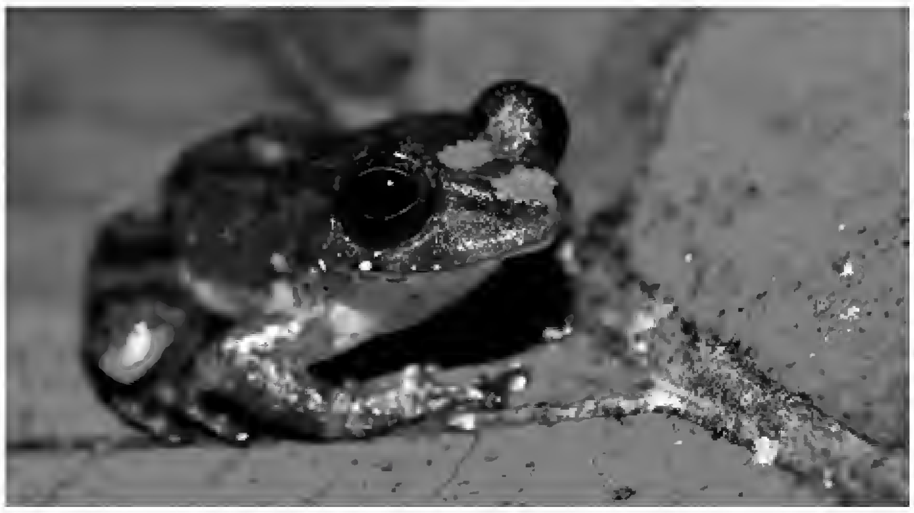

Figure 12. *Pseudophilautus sarasinorum* (Endangered).

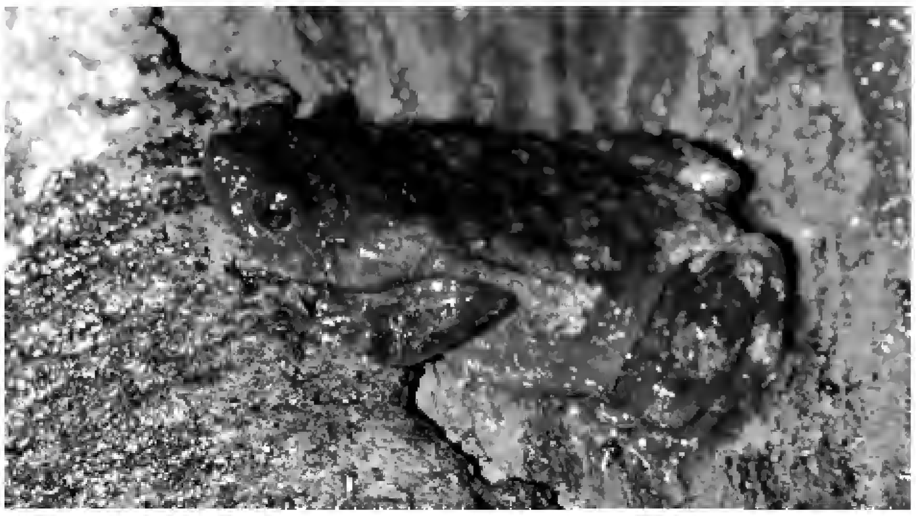

Figure 13. *Ramanella nagaoi* (Vulnerable).

Figure 14. *Taruga longinasus* (Endangered).

Figure 15. *Oligodon calamarius* (Vulnerable).

Figure 16. *Dendrelaphis schokari* (Endemic).

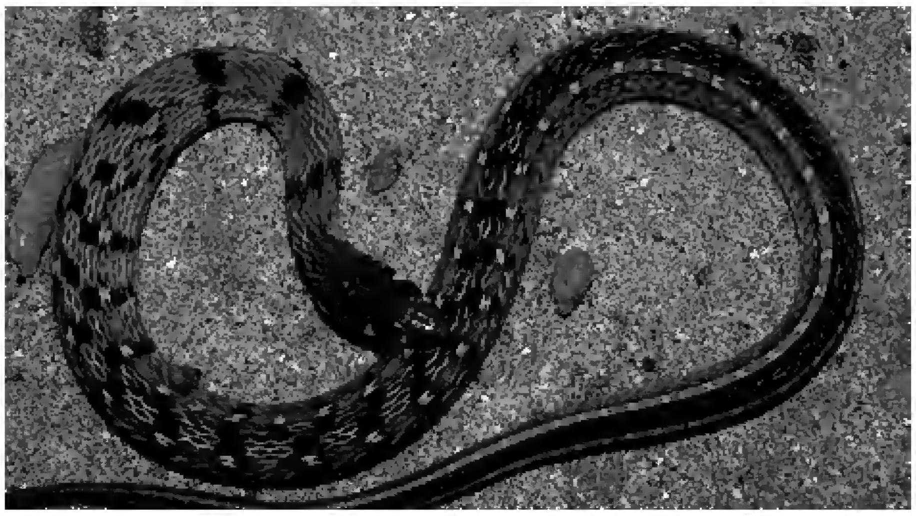

Figure 17. *Amphiesma stolatum* (red variety).

Figure 18. *Trimeresurus trigonocephalus* (plain variety).

Figure 19. *Hemidactylus depressus* (endemic).

Figure 20. Unidentified *Cyrtodactylus* cf. *subsolanus.*

Figure 21. *Lankascincus greeri* (endemic).

Figure 22. *Eutropis macularia* (common).

Figure 23. *Ceratophora aspera* (Endangered).

Figure 24. *Calotes liolepis* (Vulnerable).

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Herpetofaunal diversity and distribution in Kalugala proposed forest reserve, Western province of Sri Lanka

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***Abstract.*—Kalugala Proposed Forest Reserve (KPFR) is a primary lowland tropical rain forest, surrounded by secondary forest and vegetation disturbed by human activities such as cultivation, logging, and the collection of firewood. Herpetofaunal communities of selected different habitats (closed forest, forest edge, home gardens, and cultivations) were assessed and distribution patterns were compared. A total of 24 amphibian species (63% endemic and 33% Threatened) and 53 reptile species (38% endemic and 30% Threatened) were recorded. Overall, 763 individual amphibians and 1032 individual reptiles were recorded in this forest area. Reptilian distribution patterns are similar to amphibian distribution patterns, with the highest diversity in the closed forest and the lowest diversity in cultivations. We did not observe an effect of forest edge (edge effect) in amphibian and reptile diversity, except for forest edge and cultivations for reptiles. Adverse human activities such as improper agriculture practices, logging, and waste disposal have led to deforestation and habitat loss in KPFR.**

Key words. Amphibians, reptiles, conservation, ecology, habitats, rain forest, Sri Lanka, threats

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Introduction

Recent research has demonstrated the uniqueness of Sri Lankan fauna and its distinctness from the Indian mainland (Bossuyt et al. 2004, 2005; Helgen and Groves 2005). This is particularly true of the herpetofaunal assemblage (Bossuyt et al. 2004; Meegaskumbura et al. 2002). There are 110 species of amphibians in Sri Lanka, which belong to seven families and 19 genera with 95 (86%) endemic species. (Fernando et al. 2007; Frost 2008; Manamendra-Arachchi and Pethiyagoda 2006; Meegaskumbura et al. 2007; Meegaskumbura et al. 2009; Meegaskumbura et al. 2010; Meegaskumbura and Manamendra-Arachchi 2011). The reptile fauna consists of 210 species, including 120 (57%) endemic species, representing 24 families and 82 genera. (Bauer et al. 2007; Batuwita and Pethiyagoda 2007; de Silva 2006; Gower and Maduwage 2011; Maduwage et al. 2009; Manamendra-Arachchi et al. 2006; Manamendra-Arachchi et al. 2007; Smith et al. 2008; Somaweera 2006; Wickramasinghe and Munindradasa 2007; Wickramasinghe et al. 2009).

In the present period of mass extinction of biodiversity (Achard et al. 2002; Jenkins 2003) many species of animals, plants, and other organisms are disappearing at an alarming rate, primarily due to human activities such as deforestation (Bambaradeniya et al. 2003; Brook et al. 2003; Pethiyagoda 2005, 2007a), fire (Batuwita and Bahir 2005), erosion (Hewawasam et al. 2003), agrochemical use (Pethiyagoda 1994), and lack of systematic or scientific understanding (Bahir 2009; Pethiyagoda 2007b). Although the natural forest area of Sri Lanka still constitutes over 12% of the total land area (Tan 2005), human population density of the biologically rich wet zone is among the highest on earth (Cincotta et al. 2000). Furthermore, the population growth rate is increasing around protected areas (Wittemyer et al. 2008). Natural forests and the biodiversity have been rapidly diminishing over the past 100 years. The result has been the extinction of 21 species of amphibians, with 19 of these species being from the genus *Pseudophilautus* (Manamendra-Arachchi and Pethiyagoda 2005; Meegaskumbura and Manamendra-Arachchi 2005; Meegaskumbura et al. 2007). In addition, of the remaining species, 57 reptiles and 56 amphibians are considered Threatened (IUCNSL and MENRSL 2007).

Kalugala Proposed Forest Reserve (KPFR) is one of the remaining few wet zone forest patches in Sri Lanka and is threatened by human activities. We report the results of a study conducted in KPFR to assess species richness, abundance, and diversity of the herpetofauna and to evaluate the distribution patterns among different habitats.

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Study area and habitats

The KPFR belongs to Agalawatta and Walallawita Divisional Secretariat of Kaluthara District, Sri Lanka, which lies between 6°25'-6°30' N and 80°12'-80°16' E (Fig. 1). The floristic structure and composition suggest KPFR retain a considerable amount of primary forest. However the boundaries of this forest are disturbed due to cultivation, logging, firewood collection, and consist of secondary and disturbed vegetation. We identified four types of habitats as study sites: closed forest (Fig. 2), forest edge (Fig. 3), home gardens (Fig. 4), and cultivations (Fig. 5a, b, c).

Originally, the KPFR was an area of approxiatemly 4,630 ha when first declared a Proposed Forest Reserve in 1992. However, due to continuous deforestation, logging, agriculture practices, and illegal encroachments, the land area has drastically reduced to about 2,907 ha (Ranasinghe 1995). Several decades ago, KPFR was part of the western-most extension of Sinharaja rainforest, however, today it has been diminished to an isolated forest patch due to extensive deforestation and other human activities (Kekulandala 2002; Ranasinghe 1995). The elevation of the area ranges from 30-300 m and the majority of its precipitation originates from the southwest monsoon (April to September) with a mean annual rainfall of 4000-5000 mm. The KPFR is a catchment area for both Benthara and Kalu rivers. Average monthly temperature in the region is ~27.3 °C (Kekulandala 2002; Ranasinghe 1995).

Closed forest is found deep in KPFR and on hilltops (Fig. 6). The major vegetation formation of this habitat type can be classified as *Doona-Dipterocarpus-Mesua* series (Ranasinghe 1995). A certain degree of stratification can be identified in the forest, and although an emergent layer cannot be clearly identified, at some places the forest rises up to about 50-60 m in height and is primarily composed of *Dipterocarpus* sp., *Shorea* sp., and *Doona* sp. The canopy layer is composed of *Anisophyllea cinnamomoides*, *Mesua* sp., *Vateria copallifera*, and *Mangifera zeylanica*, that rise to about 30-40 m. The subcanopy is about 15-30 m high with the primary trees being *Semecarpus* sp., *Garcinia* sp. *Calophyllum* sp., and *Horsfieldia iryaghedhi*. The composition of the understory is variable, but primarily this layer is comprised of *Humboldtia laurifolia*, *Strobilanthes* sp., *Cyathea* sp., saplings of *Calamus* sp., and *Glochidion* sp. The ground layer is mainly composed of species in the family Poaceae and Asteraceae, as well as ground orchids. This forest harbor a rich assemblage of climbing plants (e.g., *Pothos* sp., *Entada pusaetha*, and *Calamus* sp.) and epiphytes. Exotic species like *Alstonia macrophylla* are also found in the forest and the ground is covered with a thick and moist decomposing leaf matter layer. A considerable number of streams are located in the study area (Fig. 7). Some areas of the forest are disturbed by well-maintained trails (Fig. 8) and, in some places, the forest is directly connected to cultivations.

The forest edge is the marginal area between closed forest and home gardens or cultivations. This is highly disturbed by human activities such as logging and firewood collecting. The vegetation of this area consists of a mixture of forest vegetation and home garden vegetation, trees such as *Mesua* sp., *Dipterocarpus* sp., *Shorea* sp., *Doona* sp., *Mangifera zeylanica*, *Mangifera indica*, *Caryota urens*, *Areca catechu*, *Artocarpus nobilis*, *Artocarpus heterophyllus*, *Trema orientalis*, *Syzygium* sp., *Garcinia* sp., *Murraya paniculata*, *Elaeocarpus* sp., *Macaranga* sp., *Mallotus* sp.; shrubs such as *Ochlandra stridula*, *Osbeckia* sp., *Melastoma malabathricum*; climbers such as *Calamus* sp., and tree ferns (*Cyathea* sp.). The under growth is very dense in most parts of the forest edge, where *Dicranopteris* sp. and many other fern species dominate. Species of the family Poaceae and Asteraceae were also found in the ground layer and exotic

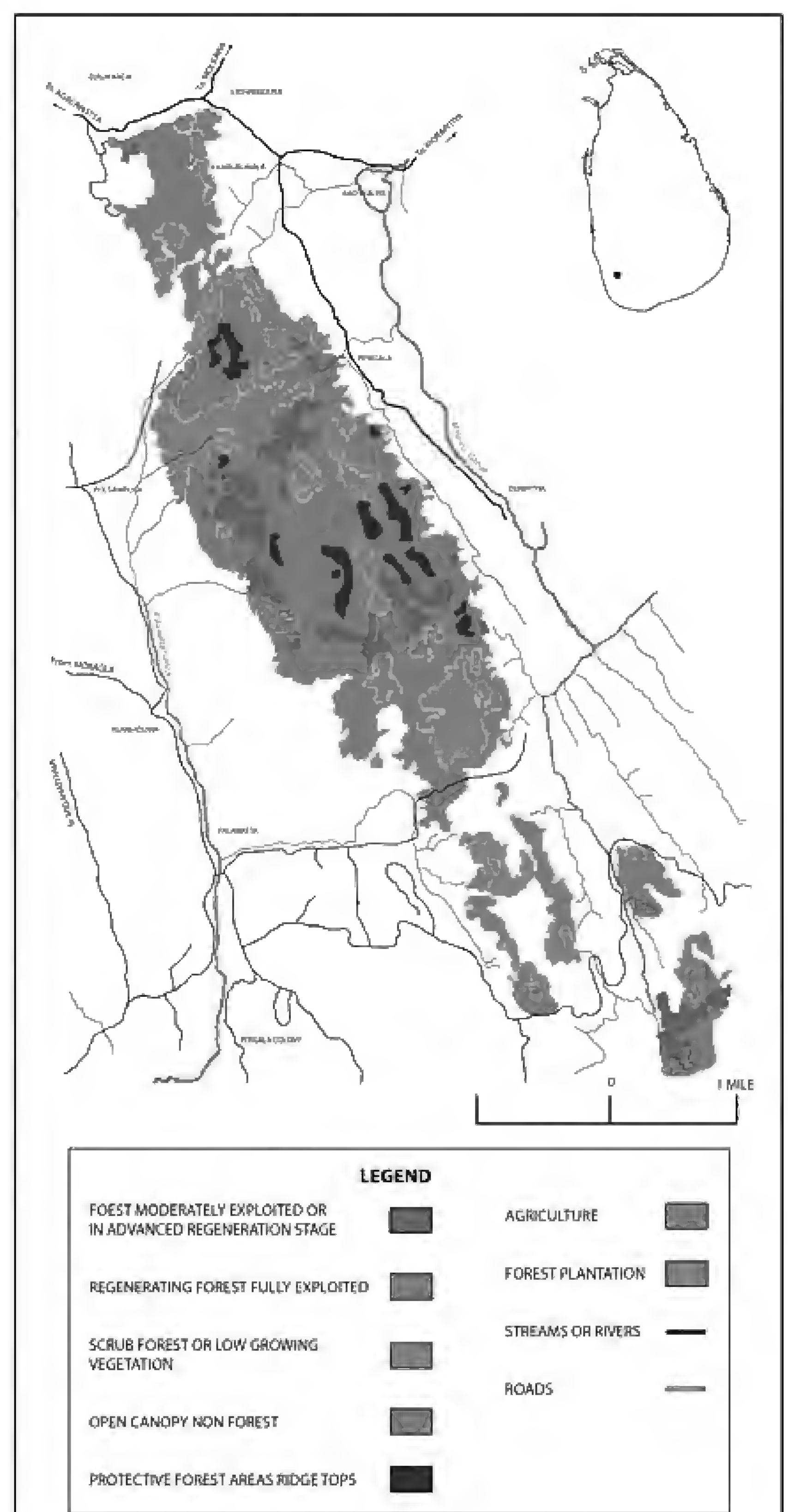

Figure 1. Geographical location and map of KPFR.

Figure 2. Closed forest.

Figure 3. Forest edge.

Figure 4. Home gardens.

Figure 5a. Cultivation (paddy).

Figure 5b. Cultivation (tea).

Figure 5c. Cultivation (rubber).

species like *Alstonia macrophylla*, *Dillenia suffruticosa*, *Eucalyptus* sp., *Acacia* sp., and *Pinus* sp. were present in this habitat type.

Home garden vegetation consists of crop, shade, and ornamental plants such as *Musa* sp., *Mangifera indica*, *Caryota urens*, *Areca catechu*, *Cocos nucifera*, *Carica papaya*, *Artocarpus heterophyllus*, *Artocarpus incisus*, *Syzygium* sp., *Garcinia* sp., *Elaeocarpus serratus*, *Macaranga peltata*, *Manihot esculenta*, *Albizia* sp., *Cassia* sp., *Nephelium lappaceum*, *Cinnamomum verum*, *Plumeria* sp., *Spondias* sp., *Piper betle*, and *P. nigrum*. Shrubs consist of *Melastoma malabathricum*, *Osbeckia octandra*, and exotic *Lantana camara*. Most home gardens are directly associated with cultivations (Fig. 9), and thus many herbaceous crop plants of the family Fabaceae, Cucurbitaceae, Poaceae, and Asteraceae, and other ornamental plants are present, as are exotic trees such as *Alstonia macrophylla* and *Acacia* sp.

Figure 6. Forest on hilltops.

Figure 7. Streams inside the forest.

Figure 8. Well maintained trails inside the forest.

Figure 9. Home gardens associated with cultivation.

The KPFR area include three main types of cultivation: paddy, tea, and rubber. Mud pools and small rivulets in paddy-cultivated land provide many microhabitats for amphibians. Around paddy and tea cultivation other crops like banana (*Musa* sp.) and coconut (*Cocos nucifera*) can be seen. Most rubber cultivations are not well maintained and the undergrowth is high and comprised of *Dicranopteris* sp., and herbaceous plants of the family Fabaceae and Poaceae. In some locations two cultivations are in close proximity with one another, such as tea and rubber, or tea and paddy (Fig. 10a, b), and in a few locations all three cultivations can be found in close proximity.

Materials and methods

Data collection

Dates of field study were determined using a random number table. A total of 12 field visits were conducted for a total of 480 hours. Visual encounter surveys and line transects (200 m) were used for data collection, including night visits with the aid of head lamps. Belt transects (4 × 50 m) used for data collection and observations conducted 20 cm deep into the leaf litter. Quadrat sampling (5 × 5 m) was employed for habitat-specific sampling, with quadrats being placed in pairs in every location of each habitat type. All quadrats were surveyed once during the day and once at night by 4-5 people moving slowly inward from the periphery. Randomly placed pitfall traps were used to sample small terrestrial reptiles where others were hand captured. Temperature and humidity were measured using a digital thermometer and a digital humidity meter, respectively. Weather, cloud cover, and canopy cover were assessed visually. In total, 24 quadrats, 12 line transects, and four belt transects were used, equating a total sampling area of 1400 m^2 + 2000 m with equal observation time being allocated to each habitat.

Data analysis

The Shannon-Wiener Index [$H' = -\sum (p_i \ln p_i)$] was used to determine the diversity of species heterogeneity (where, H' = species diversity, and p_i = proportional frequency of the i^{th} species). The non-parametric Mann-Whitney *U*-test at the 10% significant level was used to test differences in independent samples of amphibian and reptile distribution among habitats.

Species Identification

All amphibian and reptile species were identified and classified using Dutta and Manamendra-Arachci (1996), de Silva (2009), Howlader (2011), Manamendra-Arachchi and Pethiyagoda (2006), Meegaskumbura et al. (2009), Meegaskumbura et al. (2010), and Meegaskumbura and Manamendra-Arachchi (2011) for amphibians; Bahir and Silva (2005), Bauer et al. (2010a and 2010b), Das and de Silva (2005), Deraniyagala (1953 and 1955), de Silva (1990 and 2006), Günther (1864), Manamendra-Arachchi et al. (2007), Pethiyagoda and Manamendra-Arachchi (1998), Smith (1935), Somaweera (2006), Somaweera and Somaweera (2009), Taylor (1953), and Whitaker and Captain (2004) for reptiles. Plant species were identified using Ashton et al. (1997), Dassanayake and Fosberg (1980-1991), Dassanayake et al. (1994-1995), Dassanayake and Clayton (1996-2000), Gunatilleke and Gunatilleke (1990), and Senaratna (2001). The lists of Threatened species were based on the most recent national Red List (IUCNSL and MENRSL 2007).

Results

Species richness

A total of 24 species of amphibians (representing 15 genera in 7 families) were recorded, with 15 species (63%) being endemic, and eight (33%) being Threatened (Table 1). A total of 53 species of reptiles (representing 38 genera and 12 families) were recorded, with 20 species (38%) being endemic and 16 (30%) being Threatened (Table 2). The greatest species richness for both amphibians and reptiles was in closed forest, with all 24 species of amphibians being recorded there, and 45 species (85%) of reptiles. For amphibians, 23 species (96%; excluding *Pseudophilautus reticulatus*) were recorded in forest edge, followed by home gardens, and cultivations with comparatively low, 18 species (75%) and 10 species (42%), respectively. In terms of reptiles, 44 species (83%), 36 species (68%), and 25 species (47%) were recorded in forest edge, home gardens, and cultivations, respectively (Fig. 11).

Species diversity

Overall the herpetofaunal diversity and both amphibian and reptile diversity in KPFR was high. The Shannon-Wiener Index for overall herpetofauna (H'_H) was 3.838. The Shannon-Wiener Index for amphibian diversity (H'_A) was 2.508 and for reptile diversity (H'_R) 3.635 (Fig. 12a, b).

Table 1. Checklist of the amphibians (n = 24) recorded from KPFR. Abbreviations: E – Endemic; EN – Endangered; VU – Vulnerable; NT – Near Threatened; CF – Closed forest; FE – Forest edge; HG – Home Gardens; CU – Cultivations.

Scientific name	Recorded habitats			
	CF	FE	HG	CU
Ichthyophiidae				
Ichthyophis glutinosus E	x	x	x	–
Bufonidae				
Adenomus kelaartii E	x	x	x	–
Duttaphrynus melanostictus	x	x	x	x
Microhylidae				
Kaloula taprobanica	x	x	x	x
Microhyla rubra	x	x	x	–
Ramanella variegata	x	x	x	–
Dicroglossidae				
Euphlyctis cyanophlyctis	x	x	x	x
Euphlyctis hexadactylus	x	x	x	x
Zakerana kirtisinghei E	x	x	x	x
Zakerana syhadrensis	x	x	x	x
Hoplobatrachus crassus	x	x	x	x
Nannophrys ceylonensis E, VU	x	x	x	–
Nyctibatrachidae				
Lankanectes corrugatus E	x	x	x	x
Ranidae				
Hylarana aurantiaca VU	x	x	x	–
Hylarana temporalis E, NT	x	x	x	–
Rhacophoridae				
Pseudophilautus abundus E	x	x	–	–
Pseudophilautus cavirostris E, EN	x	x	–	–
Pseudophilautus folicola E, EN	x	x	–	–
Pseudophilautus hoipolloi E	x	x	x	–
Pseudophilautus popularis E	x	x	x	x
Pseudophilautus reticulatus E	x	–	–	–
Pseudophilautus stictomerus E, NT	x	x	–	–
Polypedates cruciger E	x	x	x	x
Taruga longinasus E, EN	x	x	–	–

Table 2. Checklist of the reptiles (n = 53) recorded from KPFR. Abbreviations: E – Endemic; EN – Endangered; VU – Vulnerable; NT – Near Threatened; CF – Closed forest; FE – Forest edge; HG – Home Gardens; CU – Cultivations.

Scientific name	Recorded habitats			
	CF	FE	HG	CU
Pythonidae				
Python molurus	x	x	x	x
Colubridae				
Ahaetulla nasuta	x	x	x	–
Ahaetulla pulverulenta NT	x	–	x	–
Amphiesma stolatum	x	x	x	x
Aspidura guentheri E, NT	x	x	–	–
Atretium schistosum	x	x	–	–
Balanophis ceylonensis E, VU	x	–	–	–
Boiga ceylonensis	x	–	x	–
Boiga forsteni	x	x	x	x
Cercaspis carinatus E, VU	x	–	x	–
Chrysopelea ornate NT	x	x	x	–
Coelognathus helena	x	x	x	x
Dendrelaphis bifrenalis	x	–	–	–
Dendrelaphis caudolineolatus VU	x	x	–	–
Lycodon aulicus	x	–	x	x
Lycodon osmanhilli E	x	x	x	x
Oligodon arnensis	x	x	x	x
Oligodon sublineatus E	–	x	x	x
Ptyas mucosa	x	x	x	x
Sibynophis subpunctatus	x	x	x	x
Xenochrophis asperrimus E	x	x	–	–
Xenochrophis piscator	x	x	–	–
Cylindrophiidae				
Cylindrophis maculatus E, NT	x	x	x	–
Elapidae				
Bungarus ceylonicus E, NT	x	x	x	–
Naja naja	–	x	x	x
Typhlopidae				
Ramphotyphlops sp.	x	x	–	–
Typhlops sp.	x	x	–	–
Uropeltidae				
Rhinophis sp.	x	x	–	–
Viperidae				
Daboia russelii	x	x	x	x
Hypnale hypnale	x	x	x	x
Trimeresurus trigonocephalus E	x	x	–	–
Agamidae				
Calotes calotes	–	x	x	x
Calotes liolepis E, VU	x	x	x	x
Calotes versicolor	–	x	x	x
Ceratophora aspera E, EN	x	–	–	–
Lyriocephalus scutatus E, NT	x	x	–	–
Otocryptis wiegmanni E, NT	x	x	x	x
Gekkonidae				
Cnemaspis silvula E	x	x	x	–
Cnemaspis sp.	x	x	–	–
Geckoella triedrus E, NT	x	–	–	–
Gehyra mutilata	–	–	x	x
Hemidactylus depressus E	x	x	x	–
Hemidactylus frenatus	x	x	x	–
Hemidactylus parvimaculatus	x	x	x	–
Lepidodactylus lugubris EN	x	x	x	–
Scincidae				
Eutropis carinata	x	x	x	x
Eutropis madaraszi E, NT	x	x	–	–
Lankascincus fallax E	x	x	x	x
Lankascincus gansi E, NT	x	x	–	x
Lankascincus greeri E	x	x	x	x
Varanidae				
Varanus bengalensis	–	x	x	x
Varanus salvator	–	x	x	x
Bataguridae				
Melanochelys trijuga	–	x	x	x

Species abundance

During field visits a total of 763 individual amphibians were recorded, with *Zakerana syhadrensis* being most abundant, followed by *Euphlyctis cyanophlyctis* and *E. hexadactylus*. The least abundant species were *Ramanella variegata*, *Pseudophilautus abundus*, *P. cavirostris*, *P. reticulatus*, and *P. stictomerus*, followed by *Microhyla rubra*, *Taruga longinasus*, and *Ichthyophis glutinosus*. A total of 1,032 individual reptiles were recorded with *Hypnale hypnale* being most abundant, followed by *Otocryptis wiegmanni* and *Lankascincus fallax*. The least abundant species were *Ahaetulla pulverulenta*, *Balanophis ceylonensis*, *Geckoella triedrus*, *Ramphotyphlops* sp., *Typhlops* sp., and *Rhinophis* sp., followed by *Aspidura guentheri*, *Atretium schistosum*, *Boiga ceylonensis*, and *Ceratophora aspera*.

Among habitats, abundance was greatest in the forest edge, with 269 (35%) individual amphibians and 373 (36%) individual reptiles being recorded. The lowest amphibian abundance was documented in closed forest: 158 (20%) individuals; where the lowest reptile abundance was in cultivations: 171 (17%) individuals. In home gardens, 172 (23%) individual amphibians and 215 (21%) individual reptiles were recorded, while 164 (22%) individual amphibians were recorded in cultivations and 273 (26%) individual reptiles were recorded in closed forest (Fig. 13).

Figure 10a. Closely connected cultivation (tea and rubber).

Figure 10b. Closely connected cultivation (tea and paddy).

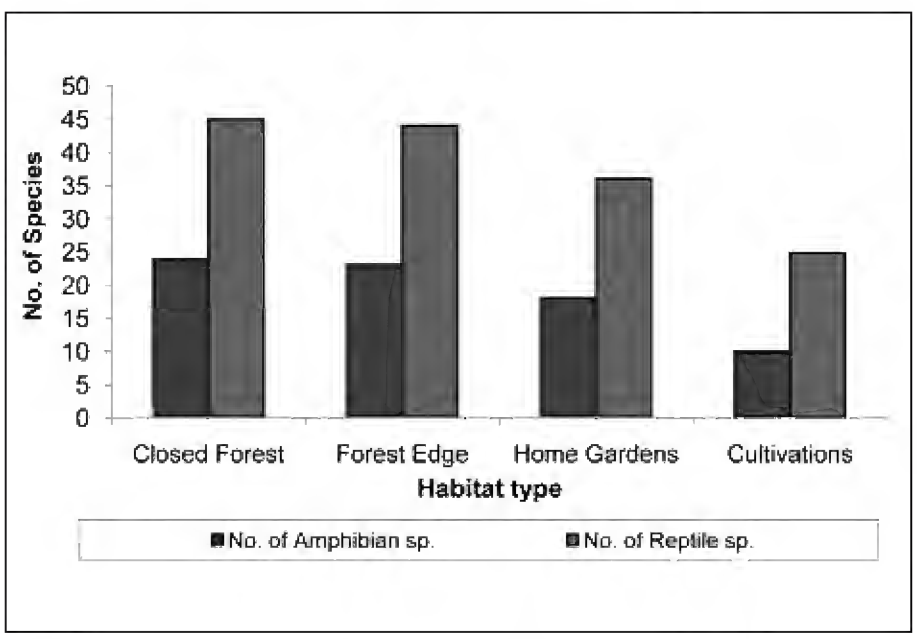

Figure 11. Number of species in different habitat types.

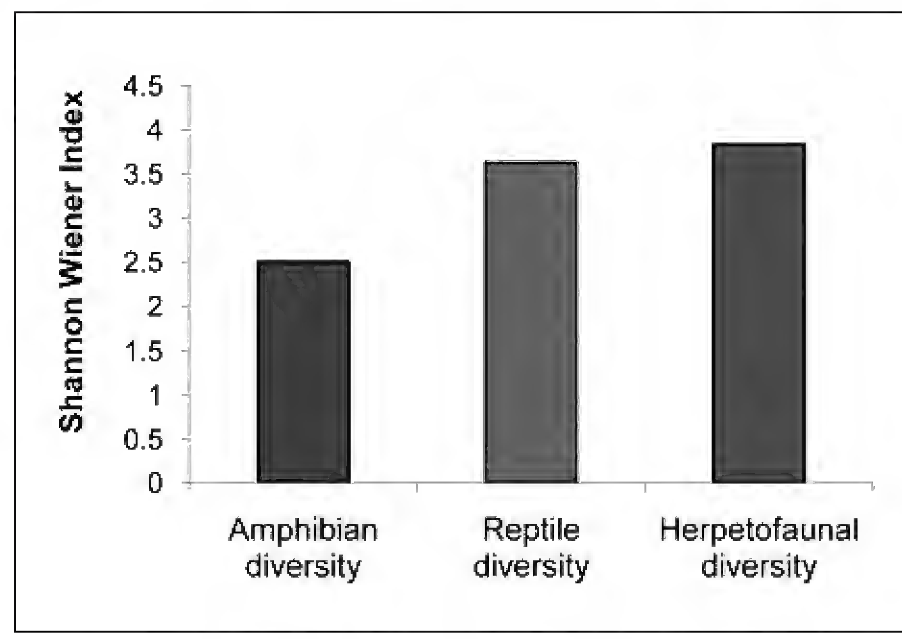

Figure 12a. Herpetofaunal diversity in KPFR.

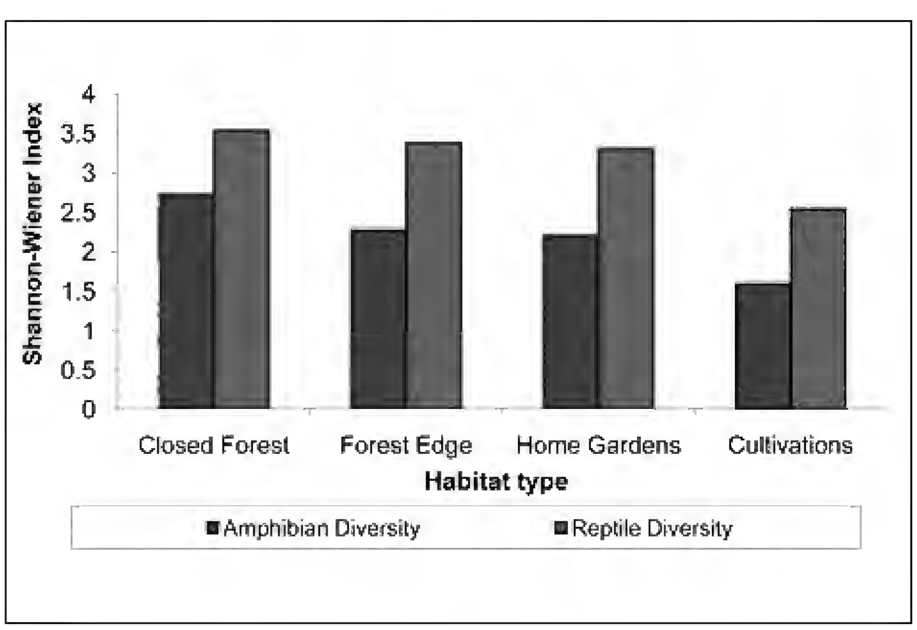

Figure 12b. Herpetofaunal diversity in different habitat types.

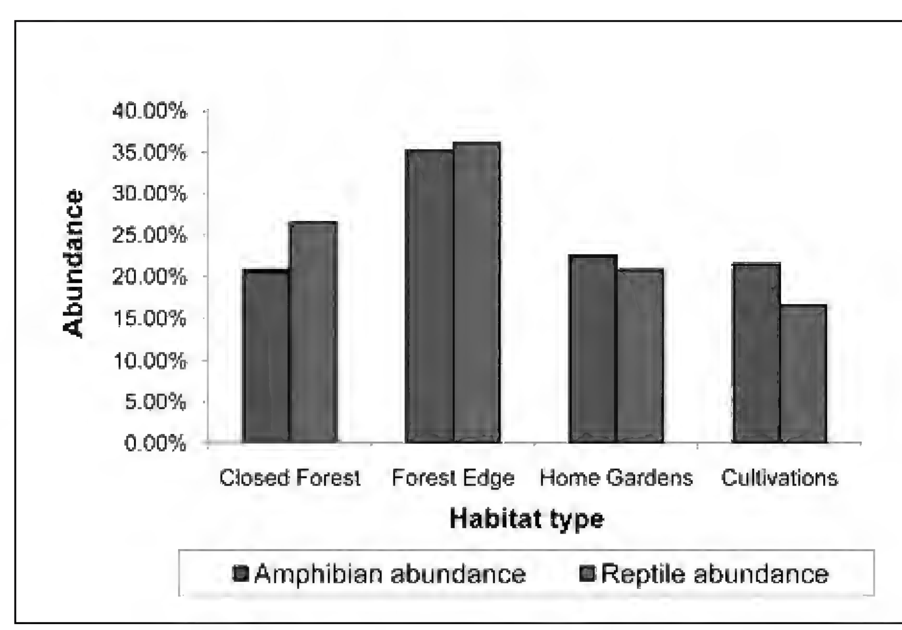

Figure 13. Species abundance in KPFR.

Species distribution

There were no significant differences in species richness of amphibians between any habitat type, however, reptiles showed a significant deference in species richness only between forest edge and cultivations (Mann-Whitney *U*-test: $Z = 2.01$, $n_1 = 44$, $n_2 = 25$, $P = 0.044$).

Discussion

Species richness of amphibians was poor in cultivated habitats such as tea, rubber, coconut, and some other commercial crops that are grown in KPFR. However, in paddy cultivations some dicroglossid frogs were found in high abundance (e.g., *Euphlyctis cyanophlyctis* and *Zakerana syhadrensis*). The higher availability of surface

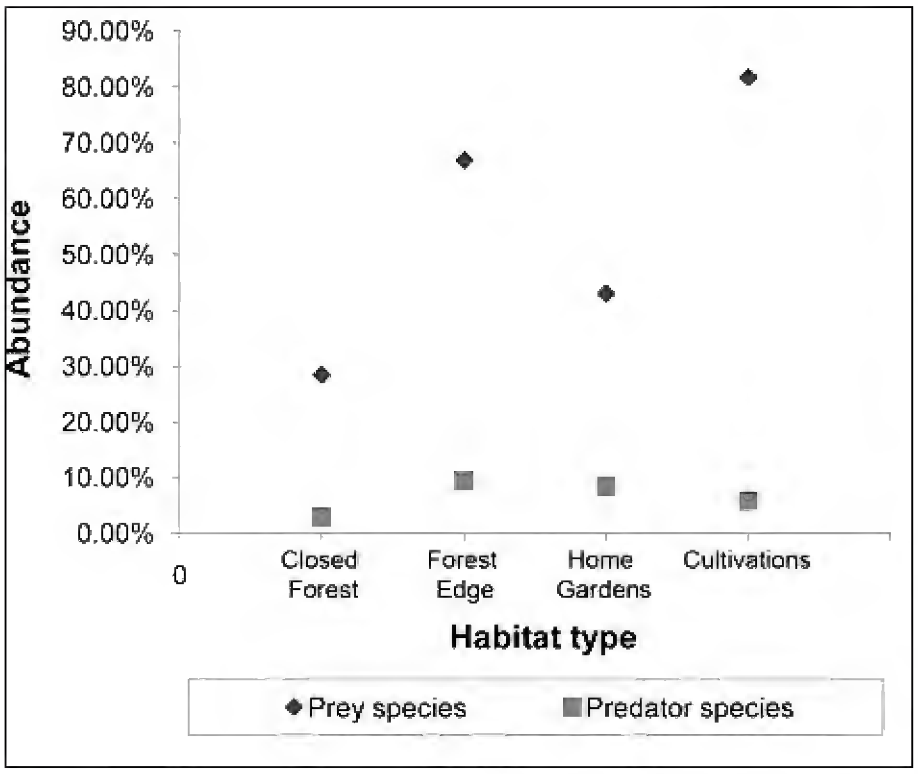

Figure 14. Distribution of some prey and predator species.

Figure 15. Deforestation inside the KPFR.

water may arguably facilitate these aquatic amphibians to thrive in paddy cultivations. *Euphlyctis cyanophlyctis*, however was most abundant in forest edge, along stream banks and water pools between edges of forest and cultivations. In home gardens, the most abundant species were bufonid and dicroglossid frogs including *Duttaphrynus melanostictus*, *Euphlyctis hexadactylus*, and *Zakerana syhadrensis*, which is likely related to favorable living conditions and high abundance of food.

Most of the endemic amphibian species (e.g., *Ichthyophis glutinosus*, *Nannophrys ceylonensis*, *Adenomus kelaartii*, *Hylarana temporalis*, *Pseudophilautus abundus*, *P. cavirostris*, *P. folicola*, *P. hoipolloi*, *P. popularis*, *P. reticulatus*, *P. stictomerus*, *Polypedates cruciger*, and *Taruga longinasus*) were mostly restricted to the forest habitats and were commonly not recorded in open areas such as cultivations and open home gardens. Interestingly, closed forest recorded the lowest amphibian abundance despite having the highest amphibian diversity, presumably due to high abundance of bufonid and dicroglossid frogs in other habitat types.

Figure 16a. Garbage dumping site of the monastery in KPFR.

Figure 16b. Garbage dumping site of the monastery in KPFR.

The distribution pattern of reptile species richness and species diversity are both similar to amphibians, the highest being in closed forest and lowest in cultivations. However, reptile abundance was highest in forest edge and lowest in cultivations, compared to amphibian abundance, highest in forest edge and lowest in closed forest. In cultivations *Hypnale hypnale* are found in high numbers potentially, which may be explained by the high abundance of prey (rodents and frogs) in those cultivated habitats. Endemic reptile species including *Aspidura guentheri*, *Balanophis ceylonensis*, *Cercaspis carinatus*, *Dendrelaphis bifrenalis*, *Xenochrophis asperrimus*, *Cylindrophis maculatus*, *Bungarus ceylonicus*, *Trimeresurus trigonocephalus*, *Calotes liolepis*, *Ceratophora aspera*, *Lyriocephalus scutatus*, *Cnemaspis silvula*, *Geckoella triedrus*, *Hemidactylus depressus*, *Eutropis madaraszi*, *Lankascincus gansi*, and *L. greeri* are mostly forest dwelling and recorded in lower abundance in other habitats, and rarely in open areas.

Edge effect encompasses biotic and abiotic changes, resulting from the interaction between two different habitat types (Murcia 1995). Extensive research on edge effect of many taxa: insects (Hochkirch et al. 2008), amphibians (Karunarathna et al. 2008), birds (Helle and

Helle 1982), and mammals (Pasitschniak-Arts and Messier 1998). However, Dixo and Martins (2008) show that edge effects do not influence leaf litter frogs and lizards in the Brazilian Atlantic forest, despite forest fragmentation. Similarly, in the present study no edge effects were detected. The only significant difference among distributions were recorded between forest edge and cultivations for reptiles (according to Mann-Whitney *U*-test). The forest edge habitats directly adjacent to cultivations have a high abundance (40%) of reptiles that prey upon amphibians. In cultivated habitats, dicroglossid and ranid frogs were found in high abundance possibly due to a number of water bodies found there (e.g., mud pools and small rivulets). Therefore, these amphibians may provide the forage base for the abundant amphibian predatory reptiles.

Edge effect also applies to succession present where vegetation is spreading outwards rather than being encroached upon. Here, different species are more suited to edges or central sections of vegetation, resulting in a varied distribution. In KPFR, many amphibian species are normally distributed in higher abundance at the forest edge rather than other habitats. These include *Ichthyophis glutinosus*, *Microhyla rubra*, *Euphlyctis cyanophlyctis*, *Zakerana kirtisinghei*, *Hoplobatrachus crassus*, *Lankanectes corrugatus*, *Hylarana temporalis*, *Pseudophilautus abundus*, *P. cavirostris*, *P. folicola*, *P. hoipolloi*, *P. popularis*, *P. stictomerus*, and *Taruga longinasus*. Reptiles such as *Ahaetulla nasuta*, *Aspidura guentheri*, *Atretium schistosum*, *Boiga forsteni*, *Chrysopelea ornate*, *Coelognathus helena*, *Dendrelaphis caudolineolatus*, *Lycodon osmanhilli*, *Oligodon arnensis*, *Sibynophis subpunctatus*, *Xenochrophis asperrimus*, *X. piscator*, *Cylindrophis maculatus*, *Bungarus ceylonicus*, *Ramphotyphlops* sp., *Typhlops* sp., *Rhinophis* sp., *Calotes calotes*, *C. liolepis*, *Otocryptis wiegmanni*, *Cnemaspis silvula*, *Cnemaspis* sp., *Hemidactylus depressus*, *H. frenatus*, *H. parvimaculatus*, *Lepidodactylus lugubris*, *Eutropis madaraszi*, and *Lankascincus greeri* have similar preferences.

The abundance of prey items is much higher than of predators in all habitats, and predators show distribution patterns similar to prey, in many instances. For example, prey species of *Euphlyctis* and *Zakerana* show a parallel distributional pattern to predator species of *Xenochrophis*, *Varanus*, and *Ptyas mucosa* (Fig. 14). Species of *Euphlyctis* and *Zakerana* live in a mutual association (Manamendra-Arachchi and Pethiyagoda 2006) and this mutual association was clearly observed in KPFR.

Near-primary forest cover accounts for less than 5% of the total wet zone land area, and what remains are small isolated patches in a sea of human development. The existing protected forests in the wet zone, which harbor a high level of biodiversity, continue to be degraded due to illegal encroachment and suffer further fragmentation leading to adverse impacts (IUCNSL and MENRSL 2007).

Adverse human activities have led to deforestation and habitat loss (Fig. 15) in KPFR. High damage has been inflicted on the forest habitat by the illegal encroachment in forests as a result of improper agriculture practices and illegal logging; this leads to loss of habitat and biodiversity. Additionally, the use of agrochemicals is a great threat to the local biodiversity, especially for the environmentally sensitive amphibians. Habitual overuse of agrochemicals in cultivation can lead to death, malformations, and abnormalities in amphibians (de Silva 2009). Most endemic and endangered species found only in closed forest are at great risk of being exterminated from the area. One specific threat is the garbage dumps of the Kalugala Monastery (Fig. 16a, b) which are located inside the forest.

The material leakage into local streams may worsen effects on biodiversity as well as the health of people that inhabit the lower reaches of streams. Material such as polyethylene bags and other non-biodegradable materials are spread around the monastery and along footpaths inside the forest. As a result of the garbage dumps, the population of *Varanus salvator* and *Sus scrofa* may have increased, thus disrupting the ecological balance.

Although these conclusions are based on the results of this study, we recommend more research be carried out for longer durations and over a larger area. We strongly suggest the relevant authorities to take immediate action to protect this valuable tropical rain forest and to declare this area a forest reserve, before implementing any long-term conservation and management plans.

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Figure 17. *Adenomus kelaartii.*

Figure 18. *Duttaphrynus melanostictus.*

Figure 19. *Kaloula taprobanica.*

Figure 20. *Microhyla rubra.*

Figure 21. *Ramanella variegata.*

Figure 22. *Euphlyctis hexadactylus.*

Figure 23. *Zakerana syhadrensis.*

Figure 24. *Hoplobatrachus crassus.*

Figure 25. *Lankanectes corrugatus.*

Figure 26. *Hylarana aurantiaca.*

Figure 27. *Pseudophilautus hoipolloi.*

Figure 28. *Pseudophilautus reticulatus.*

Figure 29. *Python molurus.*

Figure 30. *Ahaetulla nasuta.*

Figure 31. *Atretium schistosum.*

Figure 32. *Boiga ceylonensis.*

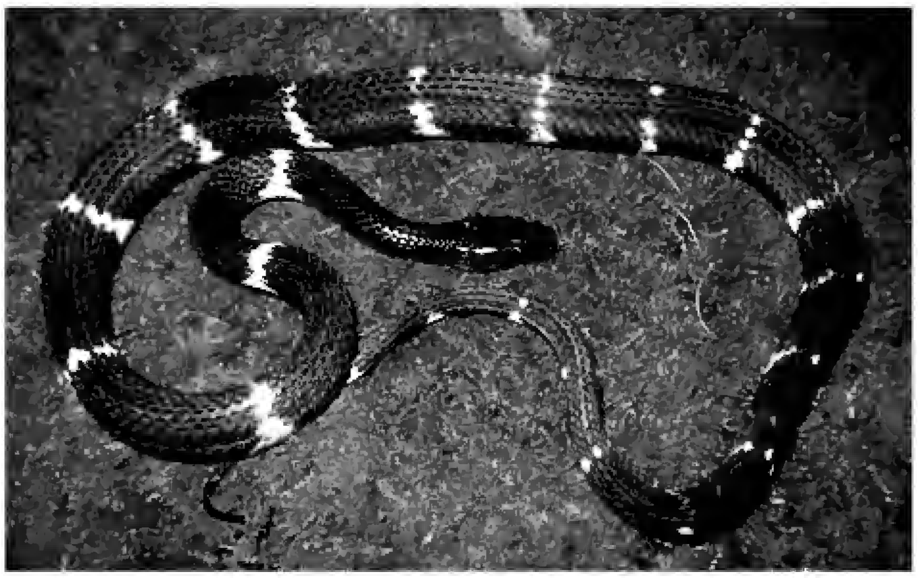

Figure 33. *Cercaspis carinatus.*

Figure 34. *Dendrelaphis caudolineolatus.*

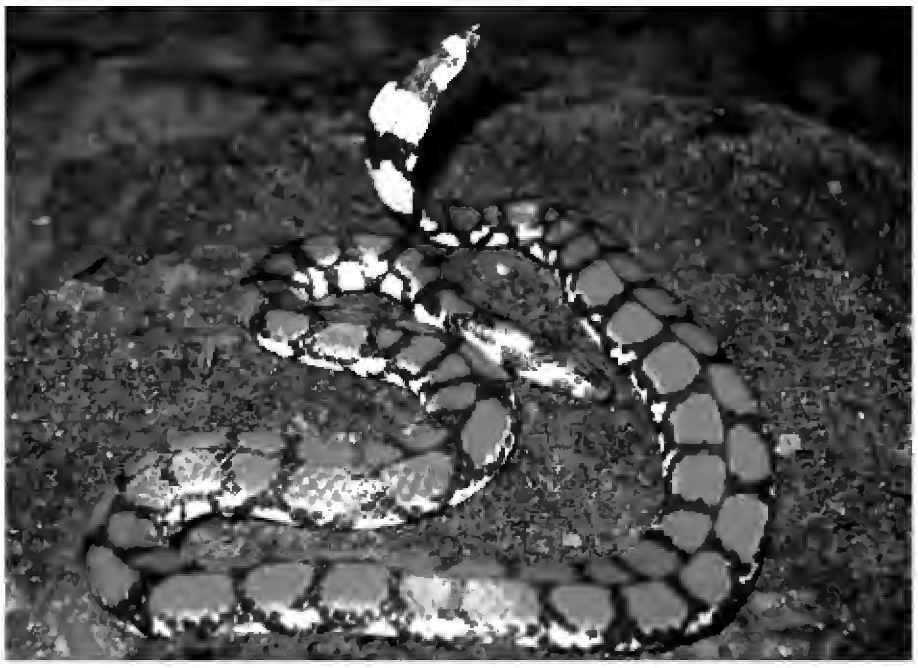

Figure 35. *Cylindrophis maculatus.*

Figure 36. *Bungarus ceylonicus.*

Figure 37. *Daboia russelii.*

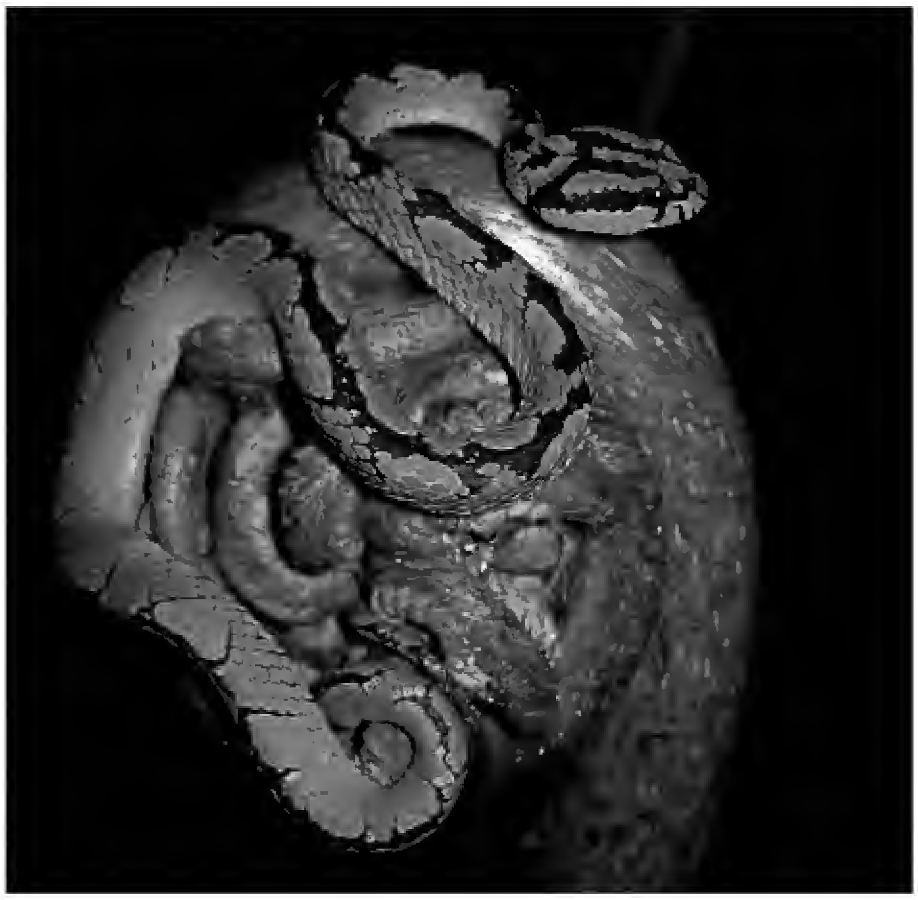

Figure 38. *Trimeresurus trigonocephalus.*

Figure 39. *Calotes liolepis.*

Figure 40. *Ceratophora aspera.*

Figure 41. *Geckoella triedrus.*

Figure 42. *Hemidactylus depressus.*

Figure 43. *Eutropis carinata.*

Figure 44. *Lankascincus greeri.*

Figure 45. *Melanochelys trijuga.*

Figure 46. *Varanus bengalensis.*

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Herpetofauna in the Kaluganga upper catchment of the Knuckles Forest Reserve, Sri Lanka

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***Abstract.*—The Knuckles Forest Reserve and forest range is a paradise for a large number of endemic Sri Lankan taxa, including a considerable number of amphibian and reptile species. A survey carried out on the western slopes of the Kaluganga catchment of Knuckles Forest Reserve recorded 19 species of amphibians and 30 species of reptiles. Of these, 15 species of amphibians and 17 species of reptiles are endemic to Sri Lanka, and 11 species are restricted to a few localities in the Knuckles forest range. Three unidentified species possibly new to science were discovered in the study, and we recommend that these species need further study for taxonomic identification.**

Key words. Knuckles forest reserve, herpetofauna, endemic, restricted, threatened, Sri Lanka

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Introduction

The Knuckles mountain range of Sri Lanka is a distinct topographic feature of the central highlands of Sri Lanka, covering approximately 21,000 ha. It lies between latitudes 7°18'-7°34' N and longitudes 80°41'-80°55' E at 900-1900 m elevation range. This landscape is made unique by the aggregation of at least 35 spectacular peaks rising above 900 m in the Kandy and Matale Districts. The Knuckles range is geologically part of the central highlands of the island but isolated from the main mountain mass by the Mahaweli River valley on the south and east and on the west by the Matale valley (De Rosayro 1958). The Knuckles range is one of the more important watersheds in the country. It receives rainfall from both the southwest and northeast monsoons. Numerous tributaries of the Knuckles contribute to major rivers, including the Mahaweli. The area's mean annual temperature outside the massif is more than 26 °C, and this value falls to about 21 °C at elevations above 915 m and to about 18.5 °C at the highest elevations (Cooray 1998).

The topographic and climatic variation in the Knuckles region has resulted in the occurrence of several natural vegetation types. According to Rosayro (1958), vegetation types of the Knuckles region are categorized as lowland tropical wet semi-evergreen forests, sub-montane tropical wet semi-evergreen forests, and montane tropical wet evergreen forests. Gunatilleke and Gunatilleke (1990) recognized 15 floristic regions in Sri Lanka, and each of these has dominant plant communities. The Knuckles forest belongs to the 12th floristic region (termed Knuckles) with a unique vegetation type. According to these authors, there are two types of natural vegetation in this region: tropical montane forests characterized by a *Calophyllum* zone and tropical sub-montane forests characterized by a *Myristica*, *Cullenia*, *Aglaia*, and *Litsea* community (Karunarathna et al. 2009).

In addition to these categories, there are anthropogenic vegetation types such as patana grasslands, which are dominated by *Cymbopogon* spp. derived from abandoned coffee and tea plantations, scrublands, and agricultural land.

The geographic location, altitude, and position of the mountain range in relation to the two main wind currents that cross the island have resulted in a unique ecosystem with an abundance of endemic flora and fauna (Kariyawasam 1991). The variety of habitats and forest communities in the Knuckles is known to harbor a diverse community of herpetofauna, but a large extent of the mountain range remains unexplored. In an effort to identify and study the distribution of amphibians and reptiles, a study was carried out in the tropical montane forests, sub-montane forests, and lowland semi-evergreen forests of the under-researched Kaluganga catchment of the Knuckles range. These forest types were derived based on elevational range (Bambaradeniya and Ekanayake 2003):

- Tropical Montane Forest (>1300 m a.s.l.)
- Tropical Sub-montane Forest (600-1300 m a.s.l.)
- Lowland Semi-evergreen Forest (below 700 m a.s.l.)

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Tropical Sub-montane Forest (600-1300 m a.s.l.).

Lowland Semi-evergreen Forest (below 700 m a.s.l.).

Tropical Montane Forest (>1300 m a.s.l.).

Methods

Fieldwork was conducted from May to July 2010 in the Kaluganga upper catchment of Knuckles range. The study area extended from the Pallegama main bridge to Kalupahana mountain area. In each habitat, data were collected from five 100 × 10 m transects, with one night sampling per habitat. The distance between transects was more than 500 m. Within each major habitat, different microhabitats (such as tree trunks, tree holes, water puddles, and other small niches) were systematically searched for herpetofauna. Three people were involved in the sampling of each transect. One person searched above 1.5 m on trees for arboreal species, while a second person pursued a terrestrial search under logs, stones, leaf litter, tree trunks, etc., and a third person searched aquatic habitats (puddles and streams). In addition to recording the different species within each transect, a thorough search for different amphibians and reptiles was carried out along nature trails or footpaths and streams outside of the five transects. The different species of amphibians and reptiles were hand-captured or collected using a hand net and observed. Frog species were located using their call signatures. Taxonomic keys (Manamendra-Arachchi and Pethiyagoda 2006; Dutta and Manamendra-Arachchi 1996; De Silva 1980; Deraniyagala 1953; Somaweera 2006; Taylor 1953) were used for identification or confirmation of collected species. Photographs of live specimens were taken in the field using a Canon EOS 350 SLR camera. After identification, the animals were released to their natural habitat unharmed.

Results and discussion

A total of 49 species of amphibians and reptiles were identified from the study sites. The survey documented 19 species of amphibians belonging to the families Bufonidae, Dicroglossidae, Nyctibatrachidae, Ranidae, and

Table 1. List of amphibians recorded during the study period from the Kaluganga upper catchment in the Knuckles (Abbreviations: * - Endemic to Sri Lanka; /R - restricted to the Knuckles forest region; CR - Critically Endangered; and EN – Endangered).

Family	Scientific name	Common name
Bufonidae	*Adenomus kelaartii* *	Kelaart's dwarf toad
	Duttaphrynus melanostictus	Common house toad
Dicroglossidae	*Euphlyctis cyanophlyctis*	Skipper frog
	Fejervarya kirtisinghei *	Mountain paddy field frog
	Fejervarya limnocharis	Common paddy field frog
	Nannophrys marmorata *, /R, CR	Kirtisinghe's rock frog
Nyctibatrachidae	*Lankanectes* cf. *corrugatus* *	Corrugated water frog
Ranidae	*Hylarana temporalis*	Common wood frog
	Hylarana gracilis *	Sri Lanka wood frog
Rhacophoridae	*Pseudophilautus fergusonianus* *	Ferguson's tree frog
	Pseudophilautus fulvus *, /R, EN	Knuckles shrub frog
	Pseudophilautus hoffmanni *, /R, EN	Hoffmann's shrub frog
	Pseudophilautus hankeni *, /R	Hanken's shrub frog
	Pseudophilautus stuarti *, /R, EN	Stuart's shrub frog
	Pseudophilautus steineri *, /R, EN	Steiner's shrub frog
	Pseudophilautus macropus *, /R, CR	Bigfoot shrub frog
	Pseudophilautus cavirostris *, EN	Tubercle tree frog
	Polypedates cruciger *	Common hour-glass tree frog
	Taruga cf. *eques* *, EN	Mountain hourglass tree frog

Rhacophoridae (15 of these species are endemic to the island; Table 1). In addition, three unidentified species of amphibians were collected; further studies are being carried out for taxonomic identification of these three species, and they may or may not be new to science. Further studies are also being carried out to identify the distribution and ecology of *Taruga eques* and *Lankanectes* cf. *corrugatus* in the region.

Among the identified species, there are seven regionally endemic species restricted to the Knuckles range, including three Critically Endangered species (*Pseudophilautus hankeni*, *P. macropus*, and *Nannophrys marmorata*) and six Endangered species (*P. fulvus*, *P. hoffmanni*, *P. stuarti*, *P. steineri*, *P. cavirostris*, and *Taruga eques*).

In this study, a total of 30 species of reptiles were recorded, with 17 regionally endemic species including four species restricted to Knuckles (Table 2). Among these, two species are Critically Endangered (*Cophotis dumbara* and *Chalcidoseps thwaitesi*) and four species are Endangered (*Calotes liocephalus*, *Ceratophora tennentii*, *Cyrtodactylus soba*, and *Lankascincus deraniyagalae*) (IUCN-SL and MENR-SL 2007).

Brief description of natural history and distribution of key species encountered during survey

Adenomus kelaartii

Endemic species to the island and found in lowland semi-evergreen forests of Knuckles forest range, primarily in riverine forests and wet patana grasslands. Species commonly observed on leaf litter and rarely recorded in semi-arboreal habitats 1.5 m above ground. Species recorded from Rambukoluwa and Manigala patana area.

Adenomus kelaartii.

Nannophrys marmorata.

Table 2. Reptiles recorded during study period from Kaluganga upper catchment Knuckles range (Abbreviations: Endemic to Sri Lanka; /R - restricted to the Knuckles forest region; CR - Critically Endangered; and EN – Endangered).

Family	Scientific name	Common name
Agamidae	*Calotes calotes*	Green garden lizard
	Calotes liolepis *	Whistling lizard/Forest lizard
	Calotes liocephalus $^{*, EN}$	Crestless lizard
	Calotes versicolor	Common garden lizard
	Cophotis dumbara $^{*, /R, CR}$	Dumbara pigmy lizard
	Ceratophora tennentii $^{*, /R, EN}$	Leaf nose lizard
	Lyriocephalus scutatus *	Lyre-head lizard/Hump snout lizard
	Otocryptis wiegmanni *	Sri Lankan kangaroo lizard
Gekkonidae	*Cnemaspis kallima* *	Ornate day gecko
	Cyrtodactylus soba $^{* /R, EN}$	Knuckles forest gecko
	Gehyra mutilata	Four-claw gecko
	Hemidactylus parvimaculatus	Spotted house gecko
	Hemidactylus depressus *	Kandyan gecko
	Hemidactylus frenatus	Common house-gecko
Scincidae	*Dasia haliana* *	Haly's tree skink
	Lankascincus deraniyagalae $^{*, EN}$	Deraniyagala's lanka skink
	Lankascincus taprobanensis *	Smooth lanka skink
	Mabuya macularia	Bronze-green little skink
	Chalcidoseps thwaitesii $^{*, /R, CR}$	Four-toe snake skink
Colubridae	*Ahaetulla nasuta*	Green vine snake
	Ahaetulla pulverulenta	Brown vine snake
	Boiga ceylonensis	Sri Lanka cat snake
	Dendrelaphis caudolineolatus	Gunther's bronze back
	Dendrelaphis tristis	Common bronze back
	Macropisthodon plumbicolor	Green keelback
	Oligodon sublineatus *	Dumerul's kuki snake
	Ptyas mucosa	Rat snake
Elapidae	*Calliophis haematoetron* *	Blood-bellied coral snake
Viperidae	*Hypnale* cf. *nepa* *	Merrem's hump-nosed viper
	Trimeresurus trigonocephalus *	Green pit viper

Lankanectes cf. *corrugatus*

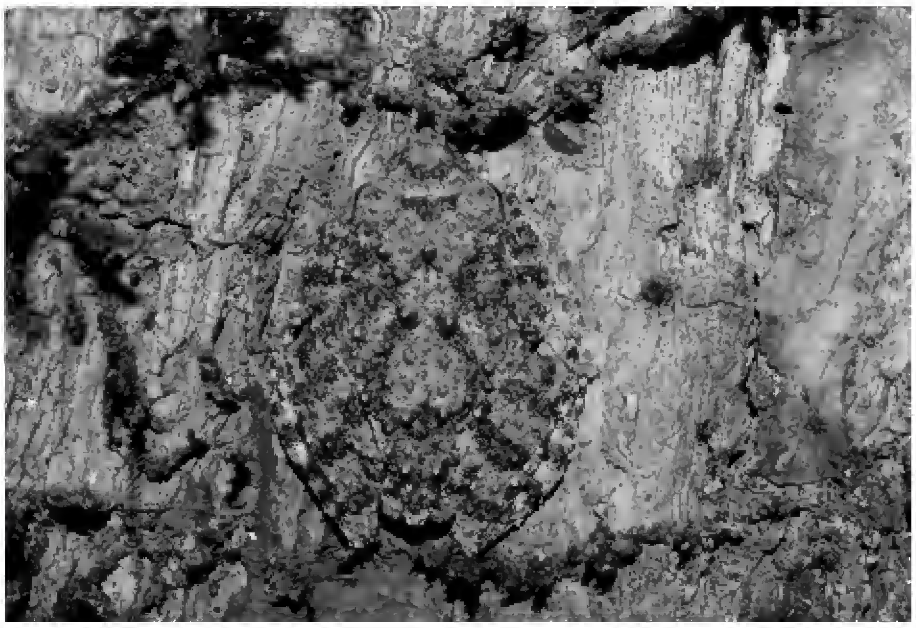
Lankanectes is a monotypic genus. Endemic species commonly found in the wet zone. Our data suggest the *Lankanectes* sp. observed in Knuckles is distinct from *L. corrugatus* found elsewhere; a taxonomic study is being carried out to understand its relationship within the genus. Recorded from montane and sub-montane forest habitats and commonly found in rocky-bottomed streams and water holes.

Nannophrys marmorata

Endemic, Critically Endangered species restricted to the Knuckles. Only recorded in Patana grasslands found within sub-montane and lowland semi-evergreen forests and in moist rock crevices. There are two other species recorded in this genus: *N. ceylonensis* found in the lowland wet zone and *N. naeyakai* restricted to the Uva and eastern provinces of Sri Lanka (Fernando et al. 2007).

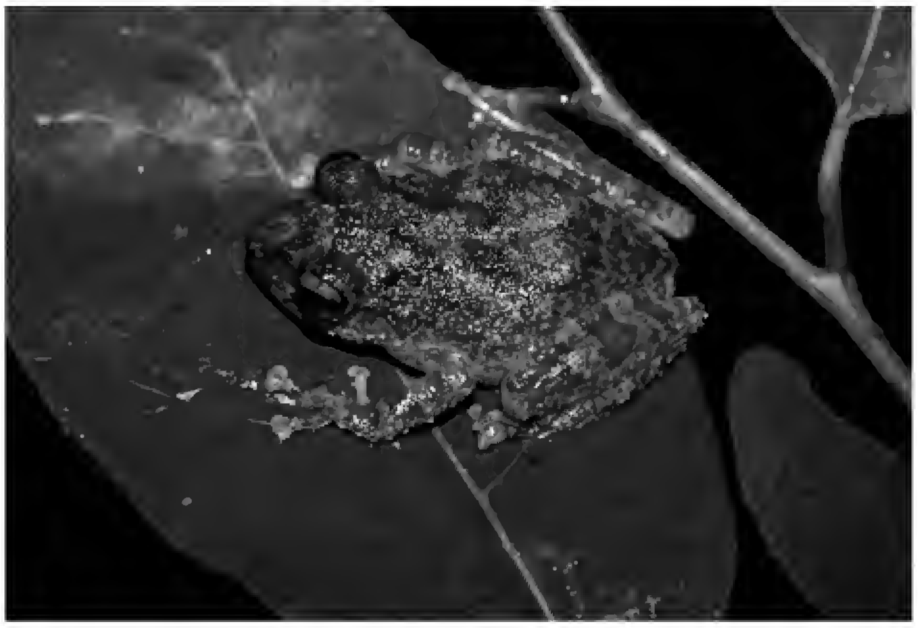
Pseudophilautus cavirostris

Endemic, Endangered species recorded from lowland semi-evergreen forests and Kaluganga riverine forests on tree trunks about 1.5-2 m above ground. Prefers to remain under thick, moist moss on tree trunks. Primarily found from Pallegama to Rambukoluwa (Kaluganga river bank).



Pseudophilautus cavirostris.

Pseudophilautus hankeni.



Pseudophilautus fergusonianus.

Pseudophilautus macropus.

Pseudophilautus fergusonianus

Pseudophilautus fergusonianus was recorded from lowland semi-evergreen forests in the study area. Endemic species primarily found on moist rock surfaces near streams during the day and on shrubs at night. Recorded in Walpalamulla and Rambukoluwa area.

Pseudophilautus fulvus

Endemic and Endangered species primarily found in sub-montane and lowland semi-evergreen forests. They occupy small tree holes during day and at night were observed on tree bark. Species recorded from Bambarakanda (near Walpalamulla). Only a single specimen was documented in this study.

Pseudophilautus hankeni

Psuedophilautus hankeni a recently described species (Meegaskumbura and Manamendra-Arachchi 2011); conservation status not assessed yet. Species only recorded from the Knuckles range and was previously recorded only in Dothalugala Man and Biosphere Reserve within the Knuckles conservation forest (Rajapaksha et al. 2006). Uncommon, arboreal species. Major habitat is montane forests living on mossy tree bark; occasionally recorded on ground. Documented from Kalupahana mountain range, Gomabaniya, and Yakungehela areas, expanding its previous range.

Pseudophilautus macropus

Endemic, Critically Endangered amphibian primarily found near streams in sub-montane forest habitats. Only one specimen was recorded during the study, collected on mossy bark, about 1.5 m from the ground in the Bambarakanda area.

Pseudophilautus stuarti

Endemic and Endangered species restricted to the Knuckles forest range found in understory of montane and sub-montane forest habitats, mostly in shrub layer. Recorded in Kalupahana peak, Gombaniya northern slope, and Bambarakanda.

Hylarana gracilis

Endemic species primarily recorded from riverbanks of lowland semi-evergreen forests. Ground-living species, recorded from banks of the Kaluganga Pallegama to Rambukoluwa rivers.

Pseudophilautus stuarti.

Calotes liocephalus.

Calotes liolepis.

Cophotis dumbara.

Calotes liocephalus

Endemic, Endangered, and arboreal, found in the Kalupahana peaks. Only a single specimen was documented in this study.

Calotes liolepis

Endemic arboreal species found on tree branches four m above ground in the Walpallamulla area. Agile and fast-moving.

Cophotis dumbara

Endemic and Critically Endangered species recorded from outside of the transect. Restricted to the Knuckles range; there are only a few records of this enigmatic species. First documentation of this species from Kalupahana mountain area. Only one specimen was recorded basking 1.5 m above ground.

Ceratophora tennentii

Ceratophora tennentii is an endemic, Endangered species, restricted to the Knuckles range. Species found in montane and sub-montane forest habitats. Semi-arboreal, found both on and above ground. Species recorded from Kalupahana, Bambaragala, and Gombaniya peaks.

Lyriocephalus scutatus

Endemic species with its major habitat in lowland semi-evergreen forests. Species found 1.5 m above ground, close to Yakungehela area. Display of deep red color is a defensive behavior in this species.

Cyrtodactylus soba

Endemic and Endangered species restricted to the Knuckles forest. Species recorded in montane forest habitats and rock crevices in Yakungehela peaks.

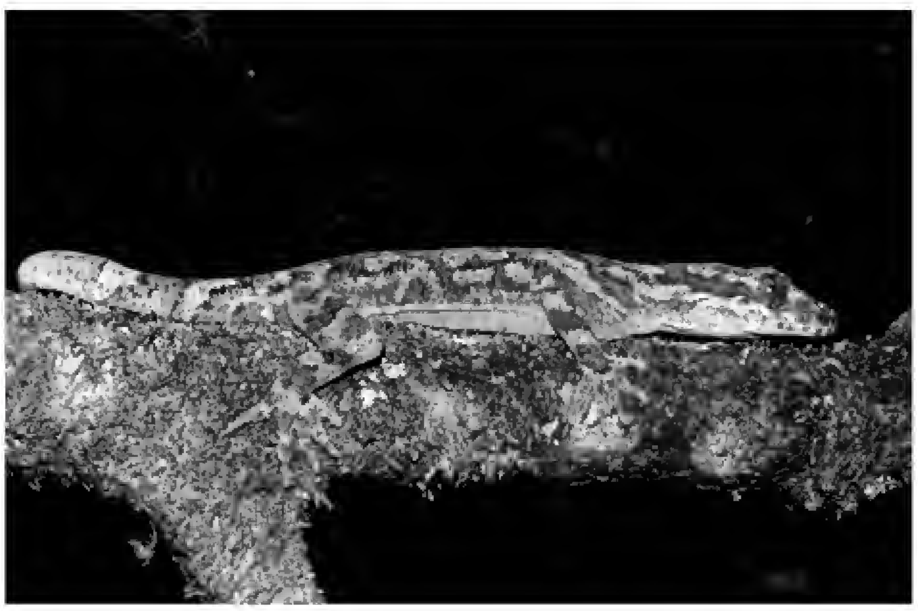
Chalcidoseps thwaitesi

Endemic and Critically Endangered species only previously recorded in a few localities in Knuckles range in lowland semi-evergreen forests. Fossorial species found under rocks in Yakungehela area.

Dasia halianus

Endemic species (Wickramasinghe et al. 2011) observed basking on tree bark in lowland semi-evergreen forests near Rambukoluwa area.

Ceratophora tennentii.



Cyrtodactylus soba.

Lyriocephalus scutatus.

Dasia halianus.

Calliophis haematoetron.

Calliophis haematoetron

Endemic, recently described species (Smith et al. 2008), and one of two species of coral snakes found in the country. Species recorded only from a few localities and Pallegama semi-evergreen forest. Fossorial form found on thick leaf litter layers.

Trimeresurus trigonocephalus

Endemic species exhibiting different color morphs and found in lowland semi-evergreen and sub-montane forests (plain green variation found). Nocturnal species, mostly found on bushes and in tree holes.

Conclusion

This survey is indicative of the importance of Knuckles range in providing refuge to a large number of amphibian and reptile species. These species are facing habitat loss, mainly due to anthropogenic activities. Forest encroachment, seasonal fires on the dry phase of the Knuckles range, illegal felling of trees, occasional gem mining, and cardamom plantations are among the threats faced by the diverse species in the Knuckles. Over several decades, the forests in the Knuckles have degraded due to cardamom planting, and to a lesser extent, by shifting cultivation and potato growing (Kariyawasam 1991). Cardamom plants thrive in shady, cool, and humid conditions at high elevations, so cardamom planters remove part of

Chalcidoseps thwaitesi.

Trimeresurus trigonocephalus.

the canopy and clear understory of the forest. These activities may be extremely detrimental to some species. In addition, similar to what is observed in the Horton Plains National Park in Sri Lanka, forest dieback also occurs in large tracts of forest in the Knuckles range. Causes of this dieback are uncertain. The resulting forest destruction and fragmentation will certainly have an adverse effect on its inhabitants. Herpetofauna in particular are extremely vulnerable to habitat changes (Pierce 1985; Wyman 1990; Blaustein et al. 1998). Furthermore, habitat loss and fragmentation due to any number of reasons will be especially detrimental to species restricted to the Knuckles. Further studies and strict conservation measures are necessary to help safeguard the herpetofauna and all the flora and fauna, that are maintaining a delicate balance in this ecosystem.

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Amphibian & Reptile Conservation 5(2):90-100.

Calotes nigrilabris Peters, 1860 (Reptilia: Agamidae: Draconinae): a threatened highland agamid lizard in Sri Lanka

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***Abstract.—Calotes nigrilabris* Peters, 1860 is an endemic arboreal agamid lizard species that is found only in montane and submontane cloud forests above 1,400 m elevation in central highlands of Sri Lanka. Here we redescribe this species based on the holotype, newly collected material, and published literature. Observations on the ecology, natural history, reproduction, and behavior of *C. nigrilabris* are noted. Two specimens of *C. nigrilabris* were recorded from Thangappuwa (~1000 m a.s.l.) in the Knuckles massif in 2003 and may represent a differentiated population needing further study. Current habitat destruction and pesticide use in local farming practices are suggested as primary threats to this species. A key to identifying members of the genus *Calotes* in Sri Lanka is provided.**

Key words. Behavior, *Calotes nigrilabris*, conservation, ecology, natural history, sauria, taxonomy

Citation: Amarasinghe AAT, Tiedemann F, Karunarathna DMSS. 2011. *Calotes nigrilabris* Peters, 1860 (Reptilia: Agamidae: Draconinae): a threatened highland agamid lizard in Sri Lanka. *Amphibian & Reptile Conservation* 5(2):90-100 (e32).

Introduction

There are eighteen species of agamid lizards in Sri Lanka, fifteen of which (83.3%) are endemic to the island (Somaweera and Somaweera 2009; Manamendra-Arachchi et al. 2006). Seven of these species belong to the genus *Calotes*, and five of which are endemic (*C. ceylonensis* Müller, 1887; *C. liocephalus* Günther, 1872; *C. liolepis* Boulenger, 1885; *C. nigrilabris* Peters, 1860; *C. desilvai* Bahir and Maduwage, 2005) (De Silva 2006). The remaining two *Calotes* (*C. calotes* Linnaeus, 1758 and *C. versicolor* Daudin, 1802) are probably widespread throughout Southeast Asia. According to published literature, the endemic *Calotes nigrilabris* is a largely arboreal species found only in montane and submontane cloud forests above 1,400 m elevation (Das and De Silva 2005; Manamendra-Arachchi and Liyanage 1994). Its conservation status is rare and vulnerable (Manamendra-Arachchi and Liyanage 1994; IUCNSL and MENR 2007). However, Deraniyagala (1953) had reported a specimen from Peradeniya (~650 m a.s.l.), at a much lower elevation than other known localities. Here we redescribe this poorly known species based on the holotype and newly collected specimens to provide more detailed taxonomic information and proper identification of species in this genus. This information is compiled into a diagnostic key for the Sri Lankan members of the genus *Calotes*. Little ecological information is available for this species, and further studies of its behavior and ecology may be important for its conservation.

Methods and materials

The material examined is deposited at the NHMW, Naturhistorisches Museum of Vienna, Vienna, Austria and Wildlife Heritage Trust of Sri Lanka (WHT), Colombo, Sri Lanka. Diagnoses and descriptions are based on external morphology. The locality records for each specimen include WHT specimen data, published locality records as well as our observations during the past decade (Fig. 1). All photographs and line drawings are displayed with the photographer and artist initials: A. Schumacher (AS), Thasun Amarasinghe (TA), Majintha Madawala (MM), Gayan Pradeep (GP), and Vimukthi Weeratunge (VW).

All measurements were taken to the nearest 0.1 mm with dial calipers (Table 1). Scale counts: SUP, supralabials were counted from the first scale anterior to that at angle of gape, not including the median scale (when present); INF, infralabials were counted from first scale posterior to mental, to angle of gape; DS, dorsal spines were counted from first spine to last of mid-dorsal row; CR, canthus rostralis were counted scales from rostral scale along scale row passing over nostril to posterior

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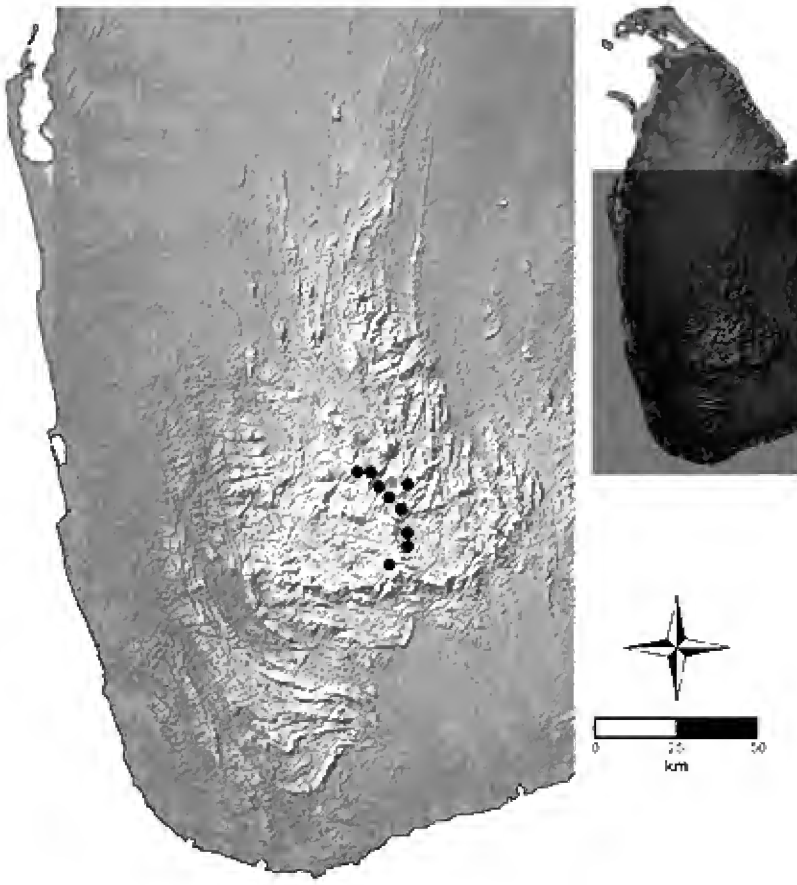

Figure 1. Current distribution patterns of *C. nigrilabris* (central highland of Sri Lanka) (red circle: type locality and black circle: other sightings).

end of supraciliary ridge; MDS, mid-dorsal scales were counted from scale behind rostral to posterior margin of the thigh; MBS, mid-body scales were counted from center of mid-dorsal row forwards and downwards across ventrals (this count is, however, made unreliable by the unequal size and uneven arrangement of the lateral scales); MVS, mid-ventral scales were counted from first scale posterior to mental, to last scale anterior to vent; SAT, spines around tympanum were counted from first spine to last above tympanum. External measurements: SVL, snout-vent length (distance between tip of snout to anterior margin of vent); HL, head length (distance between posterior edge of mandible and tip of snout); HW, head width (maximum width of head); DHL, dorsal head length (distance between posterior edge of cephalic bone and tip of snout); NFE, nostril-front eye length (distance between anterior most point of orbit and middle of nostril); UAL, upper-arm length (distance between axilla and angle of elbow); LAL, lower-arm length (distance from elbow to wrist with both upper arm and palm flexed); FL, finger length (distance between tip of claw and the nearest fork); FEL, femur length (distance between groin and knee); TBL, tibia length (distance between knee and heel, with both tibia and tarsus flexed); TL, toe length (distance between tip of claw and nearest fork); AG, axilla-groin length (distance between axilla and groin); SA, snout-axilla length (distance between tip of snout and axilla); TAL, tail length (measured from anterior margin of vent to tail tip); PAL, palm length (taken from posterior most margin of palm and tip of longest finger); FOL, foot length (distance between heel and tip of longest toe, with both foot and tibia flexed); TBW, width of tail base (greatest distance across the tail base); IOW, inter orbital width (least distance between the upper margins of orbits); ED, eye diameter (horizontal diameter of orbit); SFE, snout-front eye length (distance between anterior most point of orbit and tip of snout); SBE, snout-back eye length (distance between posterior most point of orbit and tip of snout); SFT, snout-front tympanum length (distance between anterior most point of tympanum and tip of snout); TD, tympanum diameter (least distance between the inner margins of tympanum).

Calotes nigrilabris Peters, 1860

Peters, W. C. H., *Monatsberichte der Königlichen Akademie der Wissenschaften zu Berlin*, 1860: 183.

English Name: Ceylon black-cheek lizard or Dark-lipped lizard; Sinhala Name: Kalü-kopül Katüssä or Kalü-deküpül Katüssä.

Holotype: Male (99.8 mm SVL); Cat. no. NHMW 23355; Loc. Newera Ellia: Ceylon (=Nuwara Eliya: Sri Lanka); Coll. Unknown; Date. Unknown (see Amarasinghe et al. 2009 and Tiedemann et al. 1994; Fig. 2).

Other materials examined: WHT 0380A, WHT 0380B, WHT 0380C, WHT 0380D, Nagrak Division, Nonpareil Estate, Horton Plains (06°46' N 80°47' E, 2135 m); WHT 0379, Kuda Oya, Labugolla (07°01' N 80°44' E, 1670 m); WHT 1555, WHT 2262, WHT 0536, Hakgala (06°55' N 80°49' E, 1830 m).

Diagnosis

A row of 4, 5, or 6 laterally compressed spines above the tympanum; lateral scales on the body directed backwards and downwards; dorsal and lateral scales on the body much smaller than the ventral scales on the chest and abdomen.

Figure 2. Dorsolateral view: holotype *C. nigrilabris* (Male) (NHMW 23355) Nuwara Eliya, Sri Lanka (AS).

Key to Sri Lankan species of genus *Calotes*

1. No spines above the tympanum and lateral scales on the body pointing backwards and downwards .... *Calotes liocephalus*
Spines above the tympanum present 2

2. Dorsal crest absent or less developed .... *Calotes ceylonensis*
Dorsal crest present and well developed 3

3. A row of laterally compressed spines above tympanum 4
Two separated spines above tympanum 5

4. Ventral scales larger than dorsal scales and scales on sides pointing backwards and downwards .... *Calotes nigrilabris*
Ventral scales not larger than dorsal scales and scales on sides pointing backwards and upwards .... *Calotes calotes*

5. Scales on sides pointing backwards and upwards .... *Calotes versicolor*
Scales on sides pointing backwards and downward 6

6. Gular sac present with black bands .... *Calotes desilvai*
Gular sac present without black bands .... *Calotes liolepis*

Description

(Based on the holotype and WHT collection). Length of head one and half times its width; snout slightly longer than orbit; rostral small, nasal rather large, forehead concave; cheeks swollen in the adult male; upper head scales unequal, smooth; 8 to 10 scales in canthal row, canthus rostralis and supraciliary edge sharp; a row (3-6 spines) of laterally compressed spines starting from above the tympanum and extending posteriorly beyond it; diameter of tympanum about half that of the orbit. Supralabials, 9-11; infralabials, VIII-IX (Fig. 3). Body laterally compressed; dorsal scales more or less distinctly keeled, pointing backwards and downwards (Fig. 4), except the upper two or three rows with scales smaller than the ventrals, pointing directly backwards, strongly keeled, and mucronate. Gular sac not developed, gular scales keeled, as large as the ventrals; a short oblique pit or fold in front of the shoulder covered with small granular scales. Nuchal and dorsal crests continuous, moderately developed, composed of 17-27 lanceolate spines gradually diminishing in size; the longest spines on the neck do not equal the diameter of the orbit; female with a lower crest and a mere ridge posteriorly. Limbs moderate; third and fourth fingers equal or fourth finger a little longer than the third. Relative length of fingers: 1<5<2<4<3 or 1<5<2<3<4. Forth toe distinctly longer than the third. Relative length of toes: 1<2<5<3<4. The hind limb reaches to the orbit or the temple. Tail long and slender; in the adult male it is markedly swollen at the base, with large, thick, keeled scales.

Color pattern

(Based on our observations of live specimen; not collected). The body color is green with whitish, black-edged, transverse bars or spots. Head marked with black; upper lips and cheeks usually with a black streak or separated from the eye by a white streak or with a pale bluish-green stripe running from ear to shoulder; underside of the head greenish-white, sometimes reddish-brown vertebral band present or absent; base of the tail dark olive or brown with darker-bordered light band or spots (Fig. 5).

Distribution and habitat

Calotes nigrilabris is endemic to Sri Lanka and had only been recorded from montane and submontane cloud forests above 1,400 m elevation in the central highlands. However, examination of additional specimens reveals that *Calotes nigrilabris* also occurs in the Horton Plains (Kirigalpotta, ~2200 m), which are grasslands around Nuwara Eliya, Hakgala. Thus, *C. nigrilabris* is the only *Calotes* species to occur in tropical high altitude open grasslands (Bahir and Surasinghe 2005). According to our observations *C. nigrilabris* is recorded from: Horton Plains National Park (06°46’ N 80°47’ E, ele. 2130 m); Kuda Oya, Labugolla (07°01’ N 80°44’ E, ele. 1670 m); Hakgala (06°55’ N 80°49’ E, ele. 1830 m); Nuwara Eliya (06°57’ N 80°47’ E, ele. 1710 m); Piduruthalagala (06°59’ N 80°46’ E, ele. 2300 m); Labukele (07°01’ N 80°42’ E, ele. 1525 m); Pattipola (06°51’ N 80°50’ E,

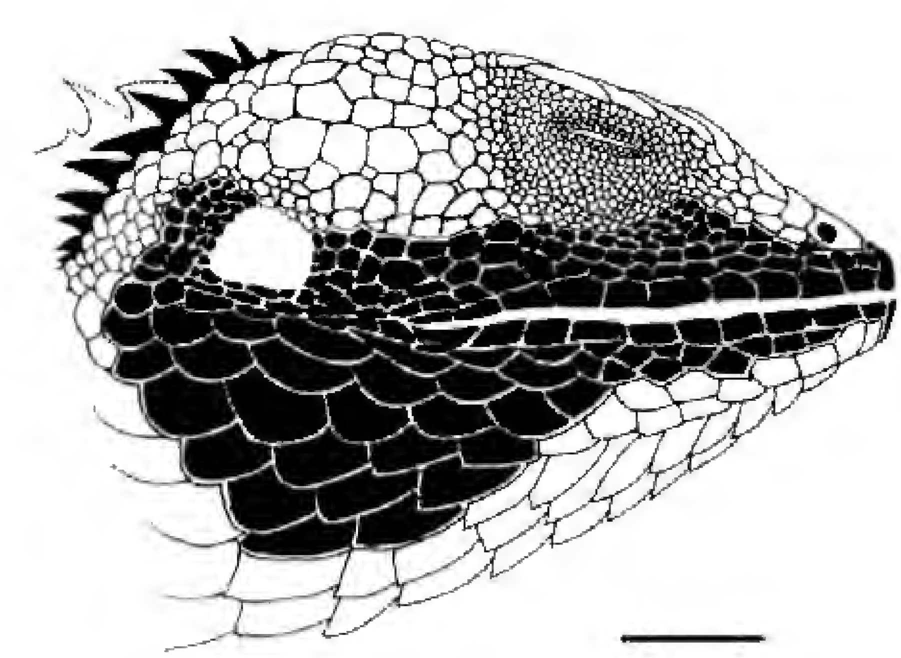

Figure 3. Lateral side view (head scalation): male *C. nigrilabris* (WHT 2262) Hakgala, Sri Lanka (Scale bar = 10 mm) (TA).

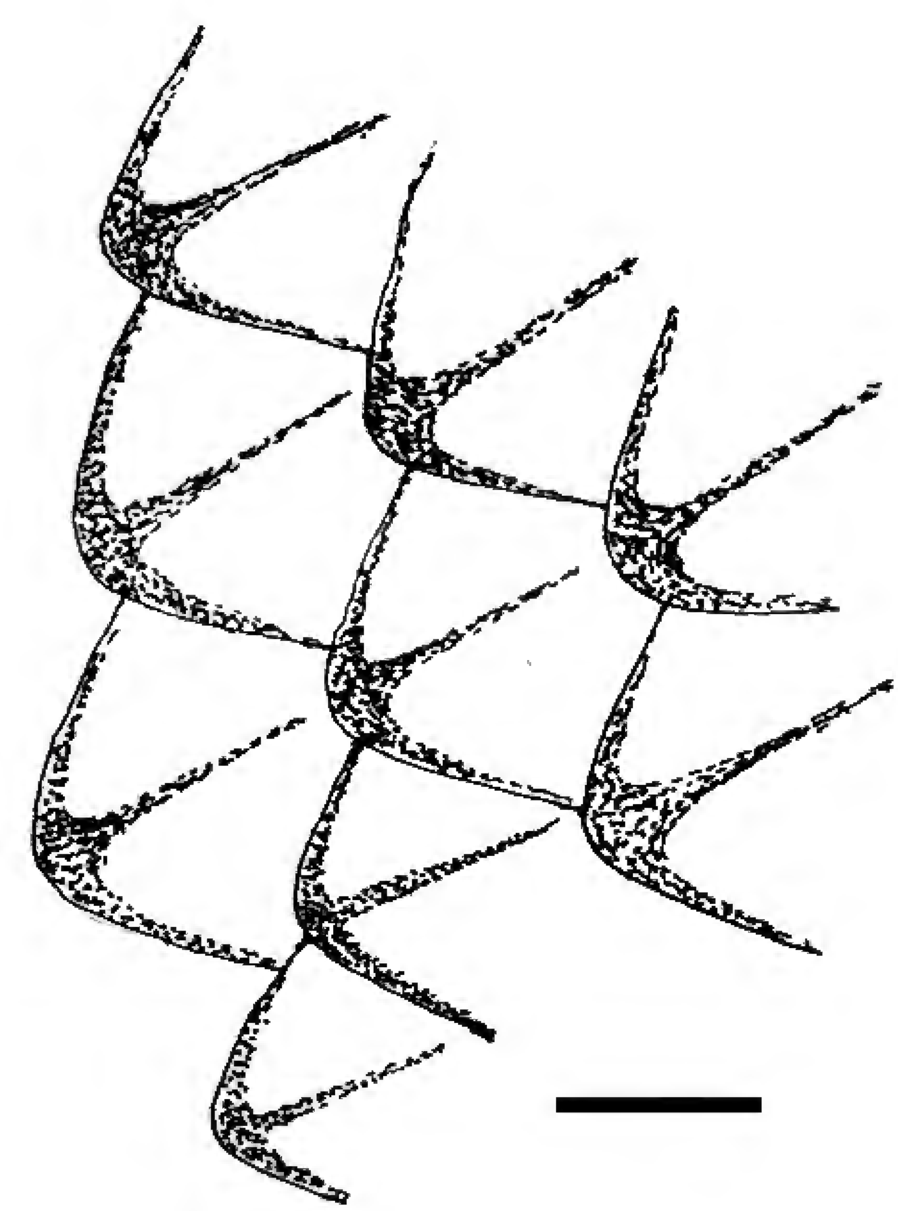

Figure 4. Mid body lateral scales pointing backwards and downwards of the male *C. nigrilabris* (WHT 0379) Labugolla, Sri Lanka (Scale bar = 1 mm) (TA).

ele. 1890 m); Ohiya (06°49' N 80°50' E, ele. 1800 m); Kandapola (06°59' N 80°50' E, ele. 1920 m); and Ragala (06°59' N 80°47' E, ele. 1980 m).

Although the Dumbara population of *Calotes nigrilabris* has long been recognized (Deraniyagala 1953), it has not been compared critically with the populations of the Central Hills. Unfortunately, the specimens from Gammaduwa in the Dumbara Hills, deposited by Deraniyagala in the National Museum of Sri Lanka, Colombo, have since been lost. However, Erdelen (1984) mentioned that he had no evidence of this species from the Knuckles, in contrast to Deraniyagala (1953). Nevertheless, we located *C. nigrilabris* from Thangappuwa (~1000 m a.s.l.) in the Knuckles Region in 2003 and observed two individuals (SVL 139.4 mm and 140.1 mm). In ongoing research, we are working to clarify whether these two populations are separate species.

Hemipenis morphology

There has been no serious attempt to classify agamid lizards based on the morphological characters of the hemipenis, even though there is an enormous diversity in hemipenal morphology. The hemipenis of *C. nigrilabris* seems less differentiated as compared to *C. ceylonensis* (Karunarathna et al. 2009) and *C. liocephalus* (Amarasinghe et al. 2009). The hemipenis of *Calotes nigrilabris* is well developed. The pedicel is slightly shorter than the head; below the head, it is broadened out into two shallowly concaved shoulders; there are no spines. The head is quadrangular in shape. It is shallowly divided longitudinally into four lobes, two being slightly larger than the others. The surface of the head is pitted in a reticulating pattern, the pits being larger on the outside and diminishing in size towards the divisions between the lobes (Fig. 6).

Reproduction

The female digs a nest hole in the ground and deposits two eggs in December (Deraniyagala 1953) and Taylor (1953) observed two ova in each oviduct and the eggs were 23 mm × 13 mm in size. We observed oviposition at Horton Plains National Park in March 2010. The female laid three eggs in the nest hole; sizes of the eggs were 17.5 mm × 10.1 mm, 17.8 mm × 10.8 mm, and 19.5 mm × 10.2 mm (average size: 18.3 mm × 10.4 mm). In September 2001, we observed another female ovipositioning at Nuwara Eliya. That female also laid three eggs; sizes of the eggs were 17.4 mm × 9.8 mm, 17.0 mm × 9.7 mm, and 17.1 mm × 9.7 mm (average size: 17.2 mm × 9.7 mm). A recent paper by Karunarathna et al. (2011) states that female *C. nigrilabris* deposit 2-4 eggs at a time.

We have successfully hatched eggs in captivity. Eggs were buried under soil in a screen-topped glass enclosure. The above four eggs were half-buried in soil and covered with leaf litter. The length of the enclosure measured 300 mm, width 150 mm, and height 100 mm. The container holding the eggs was placed in a dark and cool place (temperatures approximately 27.2-28.5°C day time and 25.7-26.4°C night). The relative humidity ranged from 62%-78% during incubation. The surface soil was generally kept dry, but occasionally about 50 ml of tap water was sprayed in the hatching enclosure to maintain a cool, humid environment similar to the original habitat.

Table 1. Measurements (mm) and counts of the male holotype (NHMW 23355), three additional males, and five females of *Calotes nigrilabris* (see measured material for specimen data).

Males (*n*=4)	NHMW 23355	WHT 0380C	WHT 1555	WHT 2262	Range	Mean ± SD
SVL	99.8	87.9	84.3	91.8	84.3–99.8	90.9 ± 5.8
HL	34.1	34.0	31.9	33.6	31.9–34.1	33.4 ± 0.9
HW	20.4	23.0	22.1	22.7	20.4–23.0	22.0 ± 1.0
DHL	25.7	25.0	26.0	24.4	24.4–26.0	25.3 ± 0.6
NFE	6.8	7.8	9.8	6.0	6.0–9.8	7.6 ± 1.4
UAL	19.1	25.8	21.7	25.5	19.1–25.8	23.0 ± 2.8
LAL	22.0	17.7	17.2	19.9	17.2–22.0	19.2 ± 1.9
FL I	5.5	5.3	4.4	7.1	4.4–7.1	5.6 ± 1.0
FL II	9.1	10.0	8.6	11.6	8.6–11.6	9.8 ± 1.1
FL III	14.7	15.1	10.2	15.8	10.2–15.8	13.9 ± 2.2
FL IV	14.4	13.9	12.4	15.9	12.4–15.9	14.1 ± 1.3
FL V	8.1	9.1	7.1	9.4	7.1–9.4	8.4 ± 0.9
FEL	23.2	28.7	23.3	29.6	23.2–29.6	26.2 ± 3.0
TBL	25.4	23.5	20.5	23.8	20.5–25.4	23.3 ± 1.8
TL I	6.5	10.5	5.6	8.2	5.6–10.5	7.7 ± 1.9
TL II	10.6	10.9	8.0	13.2	8.0–13.2	10.7 ± 1.8
TL III	17.0	12.1	15.0	18.5	12.1–18.5	15.6 ± 2.4
TL IV	20.8	14.4	16.7	21.7	14.4–21.7	18.4 ± 3.0
TL V	14.5	13.5	10.8	15.5	10.8–15.5	13.6 ± 1.8
AG	46.8	42.5	39.3	44.7	39.3–46.8	43.3 ± 2.8
SA	43.8	43.5	36.8	41.7	36.8–43.8	41.4 ± 2.8
TAL	285.7	225.0	broken	283	225.0–285.7	264.6 ± 28.0
PAL	22.1	23.2	15.1	19.9	15.1–23.2	20.1 ± 3.1
FOL	35.8	33.1	21.3	34.2	21.3–35.8	31.1 ± 5.7
TBW	10.5	11.1	10.7	12.0	10.5–12.0	11.1 ± 0.6
IOW	4.6	4.0	4.8	4.4	4.0–4.8	4.4 ± 0.3
ED	8.4	7.0	8.6	8.3	7.0–8.6	8.1 ± 0.6
SFE	11.6	8.0	10.8	10.1	8.0–11.6	10.1 ± 1.3
SBE	18.6	18.0	19.7	18.9	18.0–19.7	18.8 ± 0.6
SFT	25.4	24.8	24.6	24.2	24.2–25.4	24.7 ± 0.4
TD	3.5	6.0	3.7	5.4	3.5–6.0	4.6 ± 1.1
SUP	10	10	9	9	9–10	9.5 ± 0.5
INF	10	9	9	8	8–10	9.0 ± 0.7
MDS	65	59	66	63	59–66	63.3 ± 2.7
CR	10	10	10	9	9–10	9.8 ± 0.4
MBS	50	49	58	48	48–58	51.3 ± 4.0
MVS	57	56	103	53	53–103	67.3 ± 20.7

Table 1 continued.

Females (n=5)	WHT 0380A	WHT 0380B	WHT 0380D	WHT 0379	WHT 0536	Range	Mean ± SD
SVL	71.0	71.8	74.9	77.3	70.7	70.7–77.3	73.1 ± 2.6
HL	24.1	24.4	24.8	23.9	22.6	22.6–24.8	24.0 ± 0.7
HW	14.1	14.1	13.5	13.6	13.4	13.4–14.1	13.7 ± 0.3
DHL	19.1	18.5	19.5	19.4	18.3	18.3–19.5	19.0 ± 0.5
NFE	5.2	5.2	6.4	5.8	4.7	4.7–6.4	5.5 ± 0.6
UAL	19.8	19.1	20.3	21.8	20.6	19.1–21.8	20.3 ± 0.9
LAL	17.3	14.7	17.2	15.8	15.3	15.3–17.3	16.1 ± 1.0
FL I	6.5	6.3	5.4	6.9	6.0	5.4–6.9	6.2 ± 0.5
FL II	10.0	10.6	7.6	9.4	10.1	7.6–10.6	9.5 ±1.0
FL III	12.6	14.3	10.1	12.7	12.6	10.1–14.3	12.5 ± 1.3
FL IV	11.9	13.9	10.8	11.8	11.6	10.8–11.9	12 ± 1.0
FL V	8.8	8.5	7.8	7.9	8.0	7.8–8.8	8.2 ± 0.4
FEL	25.1	24.7	23.6	25.6	22.7	22.7–25.6	24.3 ± 1.1
TBL	19.3	18.7	18.8	20.1	18.9	18.7–20.1	19.2 ± 0.5
TL I	5.8	6.8	4.6	6.0	5.5	4.6–6.8	5.7 ± 0.7
TL II	8.5	10.8	7.7	8.8	8.1	7.7–10.8	8.8 ± 1.1
TL III	14.2	14.7	12.9	16.0	13.2	12.9–16.0	14.2 ± 1.1
TL IV	17.7	19.1	21.7	18.1	16.1	16.1–21.7	18.5 ± 1.9
TL V	12.4	13.1	9.6	12.0	12.0	9.6–13.1	11.8 ± 1.2
AG	35.6	34.8	37.1	38.6	35.9	34.8–38.6	36.4 ± 1.3
SA	34.8	33.7	33.2	33.7	29.6	29.6–34.8	33.0 ± 1.8
TAL	205	225	270	247	225	205–270	234.4 ± 22.2
PAL	16.7	15.6	13.8	15.6	18.7	13.8–18.7	16.1 ± 1.6
FOL	26.6	30.7	20.7	28.0	26.6	20.7–30.7	26.5 ± 3.3
TBW	6.8	9.1	7.4	8.4	6.8	6.8–9.1	7.7 ± 0.9
IOW	3.5	3.2	2.4	3.4	3.8	2.4–3.8	3.3 ± 0.5
ED	6.3	6.5	7.5	6.5	7.5	6.3–7.5	6.9 ± 0.5
SFE	8.8	7.8	9.9	8.8	8.8	7.8–9.9	8.8 ± 0.7
SBE	15.4	15.1	16.8	15.4	15.6	15.1–16.8	15.7 ± 0.6
SFT	19.2	19.0	19.8	18.7	18.4	18.4–19.8	19.0 ± 0.5
TD	3.8	3.7	3.4	3.6	3.6	3.4–3.8	3.6 ± 0.1
SUP	10	11	10	9	9	9–11	9.8 ± 0.7
INF	9	8	9	9	9	8–9	8.8 ± 0.4
MDS	59	64	62	59	71	59–71	48.8 ± 7.3
CR	9	10	8	8	10	8–10	9.0 ± 0.9
MBS	51	53	48	53	47	47–53	50.4 ± 2.5
MVS	61	64	57	61	51	51–64	58.8 ± 4.5
DS	24	23	21	19	17	17–24	20.8 ± 2.6
SAT	5	5	4	4	4	4–5	4.4 ± 0.5

Figure 5. Mature male *C. nigrilabris* (Nuwara Eliya) (black patch shown in cheek and small gular sac) (VW).

The lid of the container was close-fitting to deter predators (ants, etc.) and occasionally opened to spray water.

The juveniles emerged after 69 days. The emerging hatchings waited approximately one hour, with snouts extended from their shells, before rapidly exiting the egg. The newly emerged juveniles ranged from 48.1-53.6 mm in SVL and 2.5-3.2 g in weight (Table 2). After emerging from their eggs, they were very active, running in circles around the tank 10-15 times. We regularly provided small earthworms, juvenile cockroaches, and termites. During their first two days, these hatchlings only fed on earthworms and ate after breaking the prey into small parts. On the third day, these animals refused earthworms and only feed on juvenile cockroaches. They never fed on termites. Each individual ate 5-8 juvenile cockroaches per day. After approximately 10 days, the hatchlings were released in good condition to the original habitat.

Table 2. Measurements (mm) and weight (WT) in grams of hatchling *Calotes nigrilabris* in captivity (CH: Character).

CH	(1)	(2)	(3)	(4)	Range	Mean ± SD
SVL	49.7	48.1	51.3	53.6	48.1-53.6	50.7 ± 2.0
HL	11.2	12.1	11.6	11.9	11.2-12.1	11.7 ± 0.3
AG	28.6	29.6	28.9	30.1	28.6-30.1	29.3 ± 0.6
WT	2.6	2.8	2.5	3.2	2.5-3.2	2.8 ± 0.3

Behavior

Fernando (1998) mentioned that male *C. nigrilabris* gave a short hiss when handled. We also noted this hissing several times while handling this species. It is a very

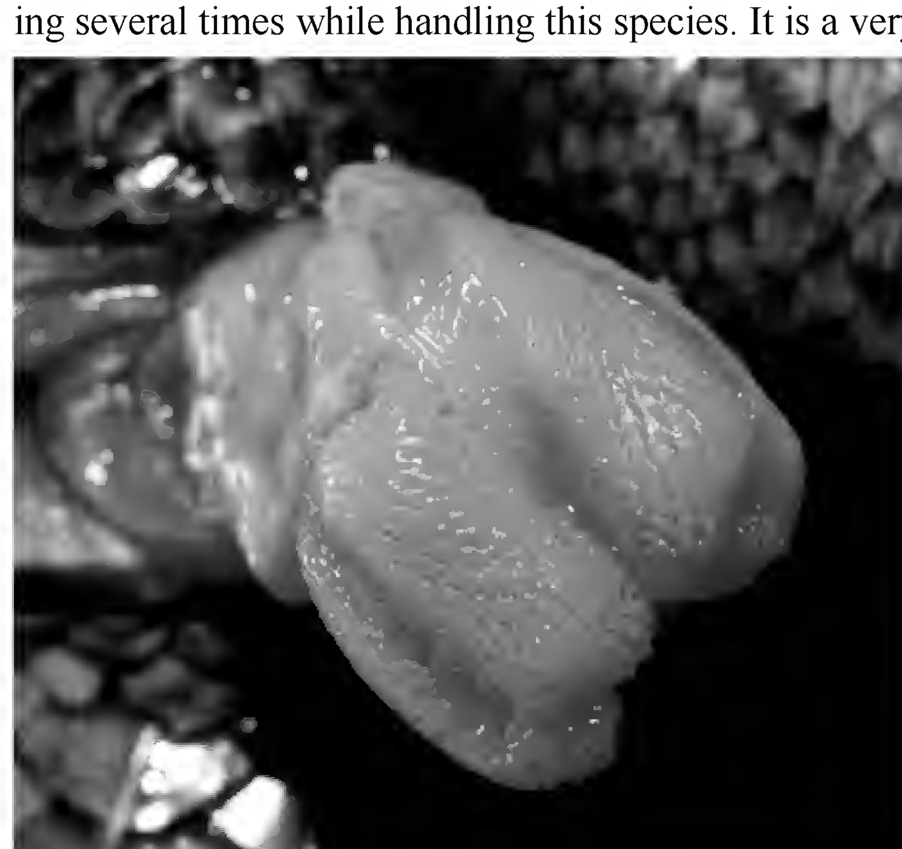

Figure 6. Left hemipenis (lateral aspect) in *C. nigrilabris* (WHT 1555) (TA).

Figure 7. Female *C. nigrilabris* on a *Rhododendron arboretum* bush (Horton Plains NP) (GP).

short, unrepeated "chik" sound, and it was only produced by males.

Hatchlings are mostly found on bushes of *Cymbopogon* sp., *Panicum* sp., *Ulex europaeus*, and *Strobilanthes* sp. and are typically light green. When disturbed or danger approaches, these hatchlings take cover in an adjacent bush. Mature individuals typically lie on endemic *Rhododendron arboreum* shrubs and when disturbed, or danger approaches, quickly jump into a nearby *Cymbopogon* sp., *Panicum* sp., *Strobilanthes* sp., or *Ulex europaeus* for refuge. This agamid lizard is usually sub-arboreal and inhabits tree trunks, hedges, and shrubs (Fig. 7) where it hunts insects and earthworms by day (Das and De Silva 2005).

Males are highly territorial and we observed territorial fighting many times on tree trunks (Horton Plains NP, Seetha Eliya, Pattipola, Agarapatana, Nuwara Eliya, Labukele, Haggala, and Ramboda). We never observed the appalling, struggling, and chasing stages of combat described by Karunarathna and Amarasinghe (2008). During the "savaging stage," they bite both fore and hind limbs, cheeks, and nuchal crest of each other. They never chased each other around the trunk while "savaging." Most often, they fight in open areas and the defeated individual jumps down from the tree and escapes.

Conservation status

According to Erdelen (1988), the average population density of *C. nigrilabris* was 220 individuals per hectare in Nuwara Eliya, and the population sizes and percentages of males, females, and juveniles were mostly stable in Nuwara Eliya. According to Karunarathna et al. (2011), the populations of *C. nigrilabris* are declining. The official conservation status of the species is Vulnerable (IUCNSL and MENR 2007).

Discussion

The threats to *C. nigrilabris* appear to stem largely from habitat fragmentation. The impact of fragmentation could be exacerbated by the fact that many important

Figure 8. Typical forest and shrub habitat of *C. nigrilabris* (Horton Plains NP) (GP).

montane forest fragments are surrounded by agricultural plantations (Fig. 8). Additionally, vegetable cultivation in Sri Lanka involves the intensive and indiscriminate application of pesticides (Erdelen 1984; Bahir and Surasinghe 2005). These fast-moving lizards are susceptible to mortality on roads (Fig. 9), and many hydropower projects and rapid urbanization are continuing to modify and fragment forest habitats. Additionally, *C. nigrilabris* has a number of predators, including the Sri Lanka whistling thrush (*Myophonus blighi*), Jungle crows (*Corvus macrorhynchos*), Greater coucal (*Centropus sinensis*), and feral cats (*Felis catus*), which were all recorded in our study areas (Karunarathna and Amarasinghe 2008; De Silva 2006; Warakagoda 1997). The crows are problematic because the local visitors to Horton Plains National Park leave their garbage, which has encouraged the migration and permanent settlement of Jungle crows in Horton Plains NP. Therefore, these crows are a threat for endemic *C. nigrilabris*, as well as other local reptiles.

The ecological and behavioral status of *C. nigrilabris* has been previously investigated by Erdelen (1978, 1984, 1988), who focused on population dynamics and distribution of the genus *Calotes* in Sri Lanka, and by Manamendra-Arachchi and Liyanage (1994), who discussed the zoogeography of the Sri Lankan agamids. The complete ovipositional behaviors of *Calotes calotes* (Gabadage et al. 2009), *Calotes versicolor* (Amarasinghe and Karunarathna 2007), *Calotes nigrilabris* (Karunarathna et al. 2011), *Calotes liocephalus* (Amarasinghe and Karunarathna 2008), *Calotes ceylonensis* (Pradeep and Amarasinghe 2009), and *Calotes liolepis* (Karunarathna et al. 2009) are documented. However, ovipositional data is lacking for *C. desilvai*.

According to Manamendra-Arachchi et al. (2006), the lowlands (elevation ~500 m) of the Mahaweli River, which separates the Dumbara Hills (= Knuckles Hills) from the Central Mountains, appears to have served as a barrier to the dispersal of highland species between the two mountain ranges. Therefore, genetic surveys of these morphologically-defined populations are needed to identify their evolutionary histories. If the Knuckles

Figure 9. Road killed sub-adult female *C. nigrilabris* (Horton Plains NP) (MM).

population is a distinct species, then that species could be critically endangered due to habitat fragmentation by Cardamom (*Elettaria cardamomum*) and tea (*Camellia sinensis*) cultivations, which also often involve the intensive and indiscriminate application of pesticides. Conservation breeding programs may be needed if the population sizes of the species continue to decline in its natural habitat.

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Territorial and site fidelity behavior of *Lyriocephalus scutatus* (Agamidae: Draconinae) in Sri Lanka

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***Abstract.*—This study on territorial behavior of *Lyriocephalus scutatus* suggests that territorial behavior is an important component of the life history of the species. *Lyriocephalus scutatus* belongs to the monotypic genus *Lyriocephalus*, and apparently its uniqueness, placing it in its own genus, extends to its strange behavior and atypical site fidelity. To understand this territorial behavior, two populations were observed while continuously recording other factors influencing territorial and site fidelity behaviors. Individual lizards performed various behaviors in their daily active periods on tree trunks and on the ground. They also exhibited highly specific synchronized territorial behavior among other individuals in the same population. Behavioral patterns differed between males and females, and the degree of "aerial horizontal distribution" of *L. scutatus* seems to be a novel behavior among lizards. Individual *L. scutatus* are highly territorial over other individuals of the same sex, as adult males observed in the study sites solely performed their territorial displays on a specific tree, whereas females occupied the largest territories.**

Key words. Territorial behavior, *Lyriocephalus scutatus*, Lyre head lizard, Sri Lanka

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Introduction

Sri Lanka is a continental island endowed with high herpetofaunal diversity and endemism. Two-hundred and seven species of reptiles have been described from Sri Lanka and more than half are endemic to the island (Somaweera and Somaweera 2009). The agamid lizard fauna of Sri Lanka is comprised of 18 species in six genera, 15 of which are endemic (Bahir and Surasinghe 2005; Samarawickrama et al. 2006): *Calotus* (six species; four endemic), *Ceratophora* (five species; all endemic), *Cophotis* (two species; both endemic), *Lyrocephalus* (one endemic species), *Otocryptis* (two species; both endemic), and *Sitana* (one species of unclear taxonomic status). Of these genera, *Lyrocephalus*, *Ceratophora*, and *Cophotis* are are considered to be relict lineages because they are confined to Sri Lanka.

In spite of the uniqueness of the lizard fauna of Sri Lanka, little is known with regard to the behavior, ecology, and natural history for most of the agamid species. This is particularly true with regard to territoriality, even though males of most species are presumed to be territorial. Among the short observation notes on territorial behavior of Sri Lankan agamids are works by Deraniyagala (1931, 1953), Smith (1935), Bambaradeniya et al. (1997), and Karunarathna and Amarasinghe (2008). However, there have been no long-term studies on territorial behavior of any Sri Lankan agamid lizard. One species, *Lyrocephalus scutatus*, is of particular interest because it is the only species of the genus and is endemic to Sri Lanka (Figs. 1 and 2). Several authors, (Deraniyagala 1931, 1953; de Silva et al. 2005; Manamendra-Arachchi 1998) reported *L. scutatus* to have territorial behaviors with males intimidating each other by opening wide their blood-red mouths showing their long sharp teeth and shaking their heads. Additionally, when threatened, they would lie motionless on their sides feigning death. A better understanding of these behaviors is necessary to more completely appreciate the unique lizard fauna of Sri Lanka and to aid in its conservation. Hence, the present study examines territorial and site-fidelity behavior of the endemic lizard *L. scutatus*.

Methods and materials

Study area

The study took place in the Gannoruwa Forest Reserve [GFR] (7º 17' N, 80º 36' E) in Kandy district in the Central Province of Sri Lanka (Fig. 3; modified from Wickramasinghe 2006). The reserve is a remnant forest patch covering an area of ~250 acres and is surrounded by villages. The vegetation within the GFR can be grouped into

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natural forest, naturalized plantations (i.e., abandoned cocoa, tea, coffee, *Artocarpus heterophyllus*, etc.), grasslands, and mahogany plantations. Home gardens comprise most of the anthropogenic ecosystems bordering the reserve. Observations were made at two sites within the GFR. Site A at Pallegama (07º 28' N and 80º 60' E) is a high canopy home garden that is very well shaded by the common tree *Myristica fragrance* (Fig. 4) with a moderate to steep slope (30º average). Site B at Yatihalagala (07º 36' N and 80º 52' E) is also a shady habitat, but with greater human interference than study Site A since it is nearer to human settlements (Fig. 5). Garmin (GPS12) was used to obtain geographical coordinates and Brunton clinometers (Brunton Company, USA) were used for measuring slope.

Methods

Detailed studies started in mid October, 2005, and were conducted until late February, 2006. Both field sites were partitioned into a grid of 1 × 1 m quadrats using small PVC stumps to mark the coordinates so locations of lizards could be determined within 0.25 m. Two template grid maps were created, one for each of the study sites. Each lizard observed was captured, sexed, measured, and given an identifying name. To permit identification of individual lizards from several meters away, all individuals observed and captured, within the study areas, were temporarily marked using loose elastic bands of various colors placed on the waist. Three reproductive classes were recorded: adult males, adult females, and subadults. Adult males and females were defined as individuals that were sexually mature (i.e., >80 mm snout to vent length [SVL] and with fully grown rostral knob and crest). Subadults were defined as individuals that were not in breeding condition (i.e., <80 mm SVL and less developed rostral knob and crest). Direct visual observation of natural populations was aided, when necessary, by the use of a pair of Nikon 10 × 8 binoculars. Focal population sampling was conducted by observing the entire population continuously for 20 to 60 minutes; thus the observed focal time for individual animals of a particular population was equal. If a particular animal was not located during the entire sampling it was considered "Not Observed."

In order to gather detailed information on spatial distribution, censuses were conducted three times a month by traversing the entire field site. Trees in which lizards were observed were scanned throughout the day (0600 to 1800 hr) and the locations of all lizards (marked or unmarked) were recorded. All behaviors observed, including both those exhibited in isolation and those directed towards other individuals, were recorded and all individuals involved in social interactions were noted. A total of 110 hours was spent performing the censuses.

Herein, an individual lizard's territory is considered to be the area that encompasses all positions of the lizard, day and night. Thus, all locations where individuals were observed during the study period (including incidentally observed individuals) were recorded and mapped for the calculation of the size of the territory. Territories are graphically displayed as polygons with inside angles ≤180º hand-drawn around the outermost observed coordinates. In addition, all woody surfaces of trees where lizards were recorded were added to the area of the territory using average cylindrical area representing the trunk of a tree (Philibosian 1975). Since we have repeated measurements of the same individuals on different days, and multiple individuals from the same site (spatial autocorrelation) data were analyzed statistically as a linear mixed effects model using software R-2.9.0-win32. Microsoft Office Excel 2007 was used for the graphical display of data.

Results

Observed behaviors

A total of 180 focal animal samples were recorded from 12 marked individuals (six males, three females, and three subadult males) on 15 days (including night visits) over a six-month period in the pre-reproductive season of these lizards. The marked population at Site A consisted of five individuals (two males, one female, and two subadults). The marked population Site B consisted of seven individuals (four males, two females, and one subadult). All behaviors demonstrated, including both those exhibited in isolation and those directed towards other individuals, are summarized in Table 1.

Table 1. Summary of commonly observed behaviors of lizards in their natural environment.

Behaviors	Description
Body-lift	Uplift on all four limbs pushing body off surface followed immediately by descent, repeated frequently; other lizards may or may not be seen in the vicinity.
Gular Sac Display	Gular sac is extended with lateral side compression accompanying a *Body-lift*.
Head-bob	Relatively rapid up-and-down movement of the head or head and neck region only; gular sac may also be extended.
Tail-wag	Undulating movement of tail.
Still	Positioned on the surface without notable movements.
Adjustment	A simple change in still position.
Walking	Moving about in an area slowly.
Feeding	Taking in a food item.

Figure 1. *Lyrocephalus scutatus* – male.

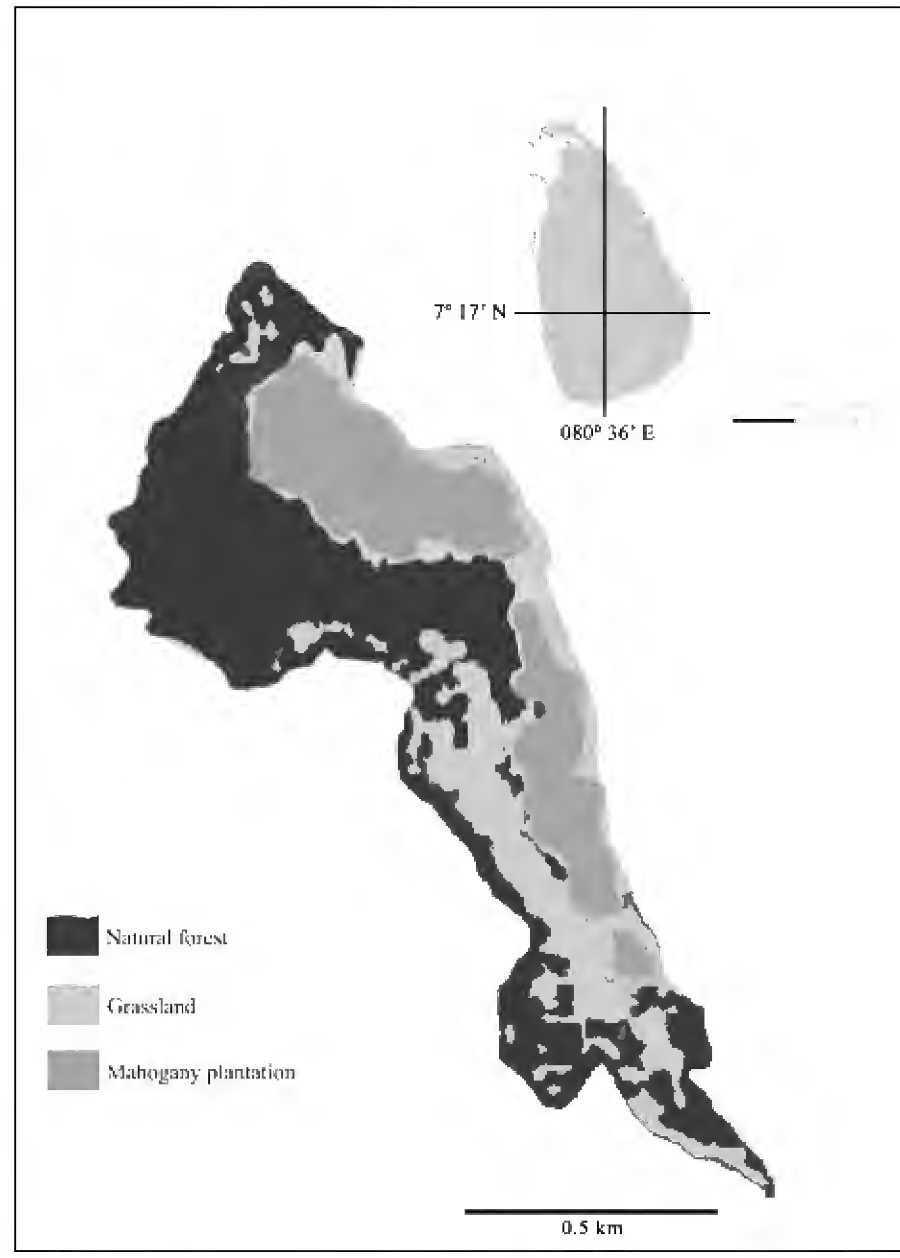

Figure 3. Map of Gannoruwa Forest Reserve - Kandy district Sri Lanka.

Figure 2. A lizard threat pose – *Body-lift*, *Gular Sac Display*, and *Head-bob*.

Figure 4. Study site A - Gannoruwa Pallegama.

Figure 5. Study site B - Gannoruwa Yatihalagala.

Figure 6. Different behaviors observed: *Body-lift*, *Gular sac display*, and *Head-bob* with *Body-lift*.

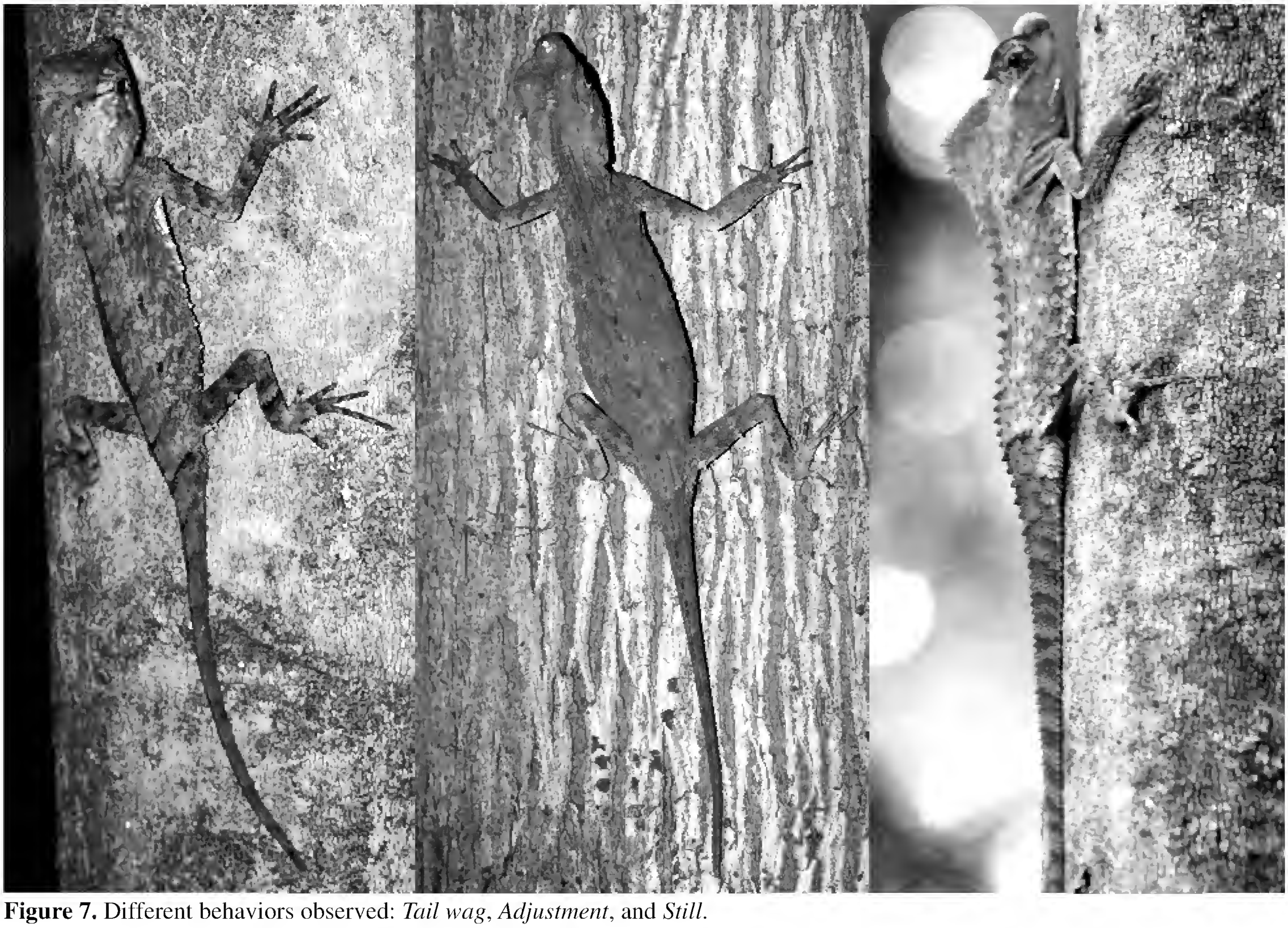

Figure 7. Different behaviors observed: *Tail wag*, *Adjustment*, and *Still*.

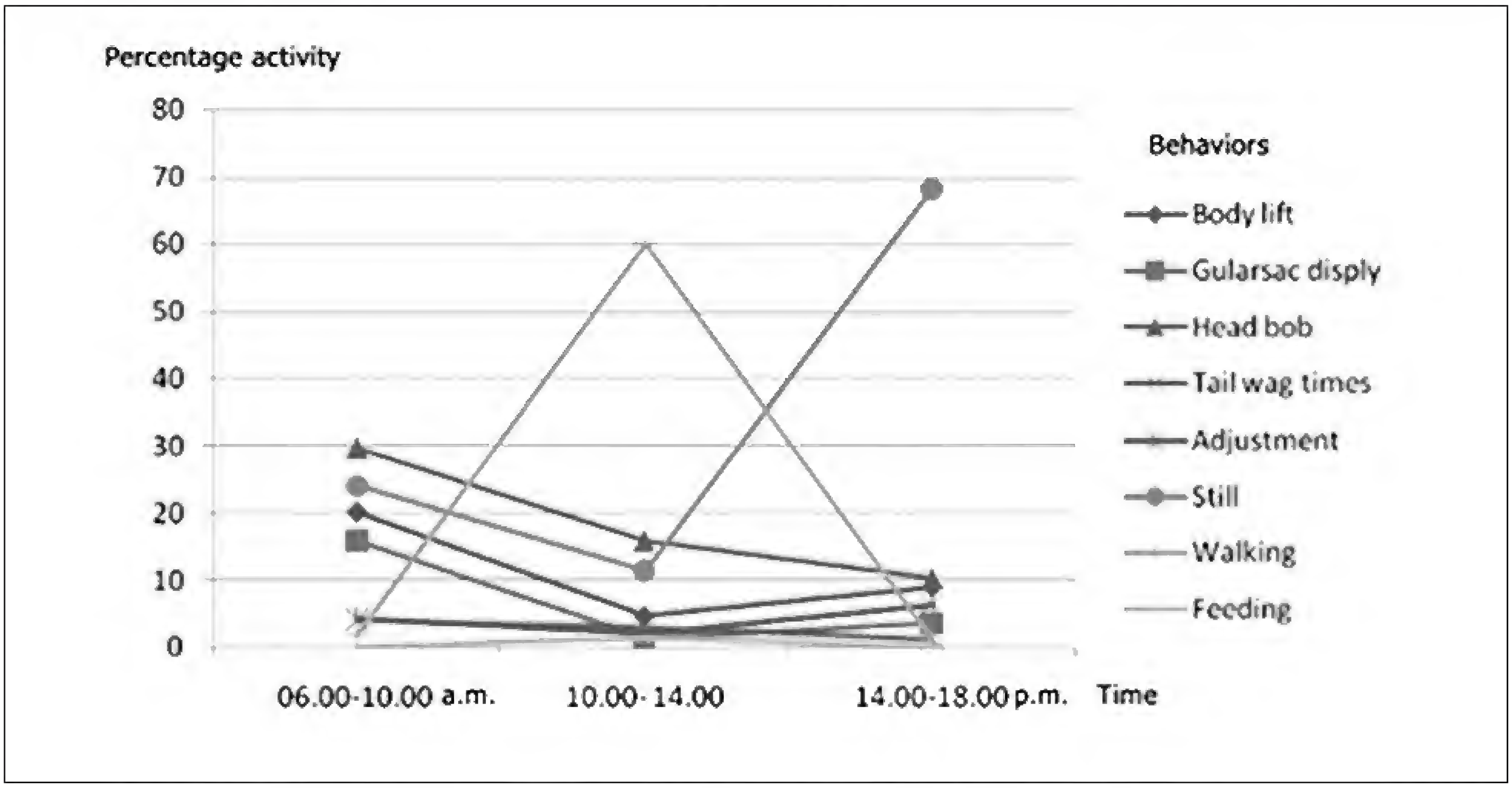

Figure 8. Percentage of various behaviors displayed by *L. scutatus* according to time of day.

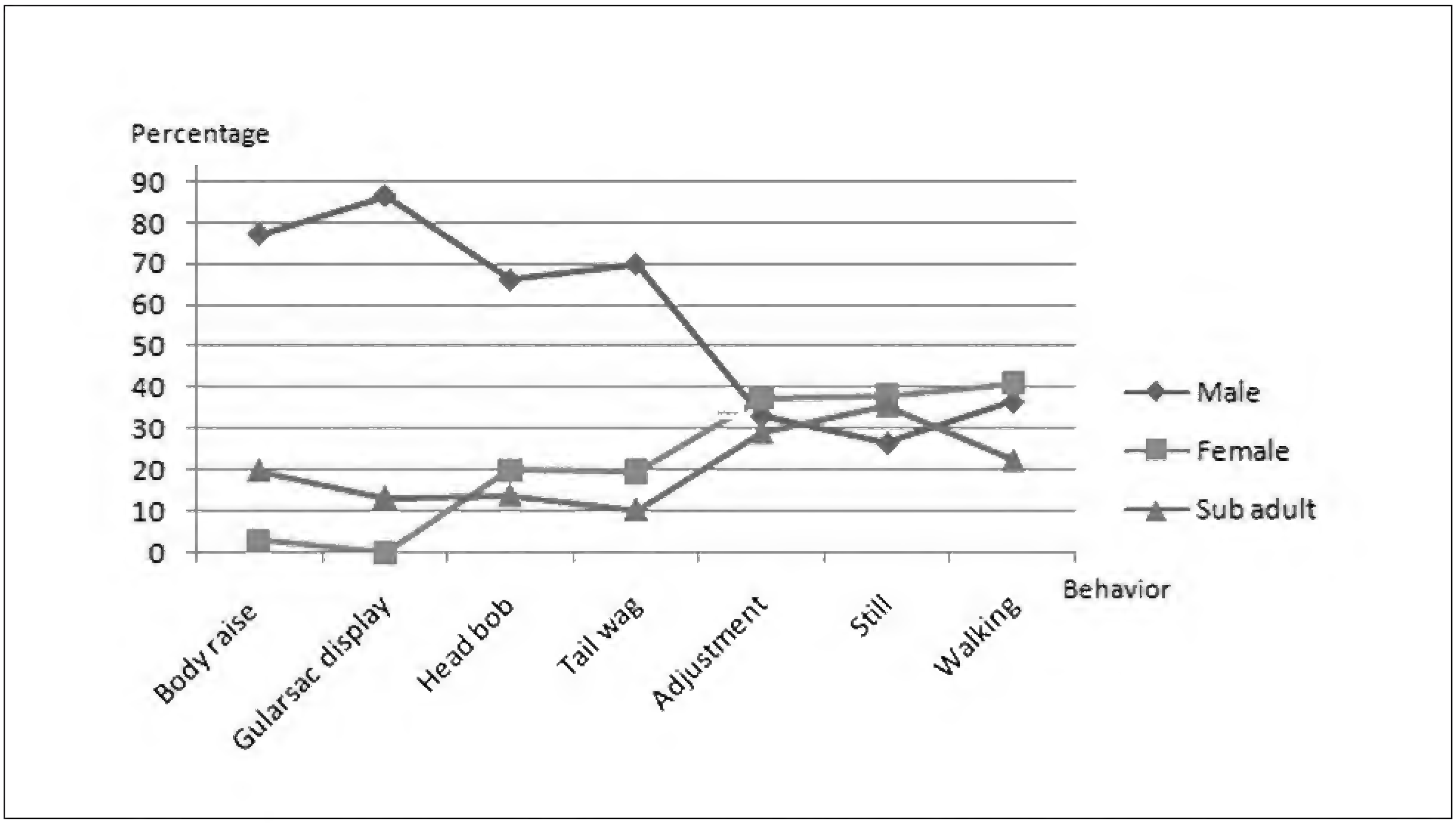

Figure 9. Percentage of time spent exhibiting various behaviors for the different reproductive groups of *L. scutatus*: males, females, and subadults.

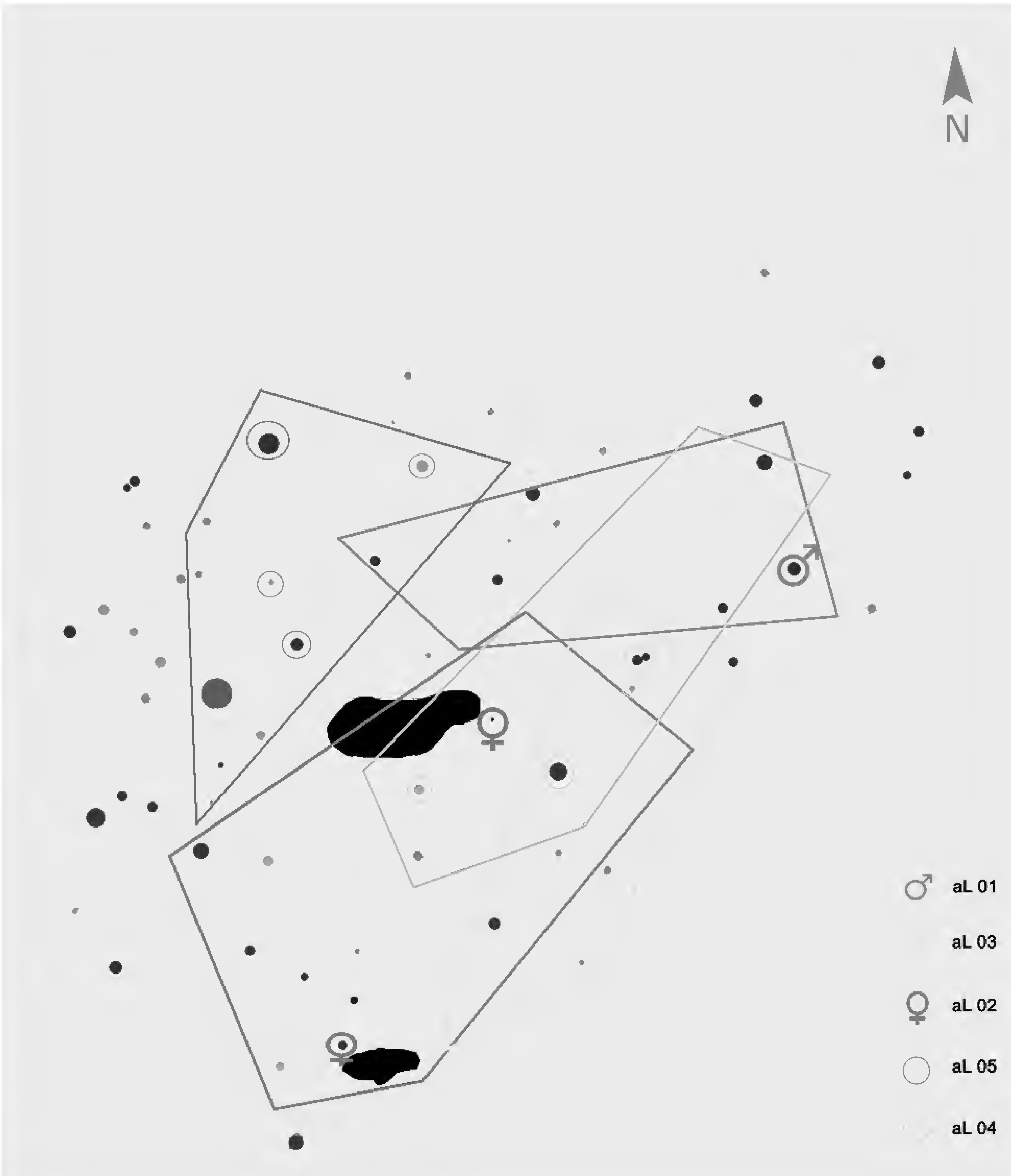

Figure 10. Map of individual territories of lizards in site A.

Table 2. Percentage of overlap of territories between individuals according to reproductive category.

Category	Male	Female	Subadult
Male	<1.0%	40%	20%
Female	48%	00%	11%
Subadult	15%	18%	00%

Several different behaviors were observed during lizard activity periods (Figs. 6 and 7). Generally, displaying would begin in the morning and continue for several hours until the displaying lizards would climb down from trees to the ground. In the evening, lizards would climb-up the trees and start displaying again until they would go to sleep at nightfall. When an individual lizard did not comedown from the tree, it remained there in the *Still* position the entire day. When lizards were displaying they performed their behaviors in an upright position on the tree trunks. *Body-lift*, *Gular Sac Display*, *Head-bob*, and *Tail-wag* were frequently performed in the upright position, however *Head-bob*, *Body-lift*, and *Tail-wag* were also performed on the ground while performing *Walking* or *Feeding*.

The meeting of two different individuals was not observed during the six-month study period. On one occasion, a female was found with a male on the same tree, but no remarkable behaviors were observed between those two individuals, although the male did display its usual behaviors.

Behavioral differences among reproductive groups

Time spent performing the various behaviors differed with the time of the day (Fig. 8). Behaviors such as *Head-bob*, *Body-lift*, *Gular Sac Display*, and *Still* were common in the morning hours from 0600 to 1000 hr. *Feeding* was not observed during this morning time period and only a small amount of time was spent *Walking*. *Tail-wag* and *Adjustment* were also performed in the morning. During daytime, from 1000 to 1400 hr, *Walking* increased to about 60% of the behavior of *L. scutatus*. All the other behaviors observed in higher proportion during

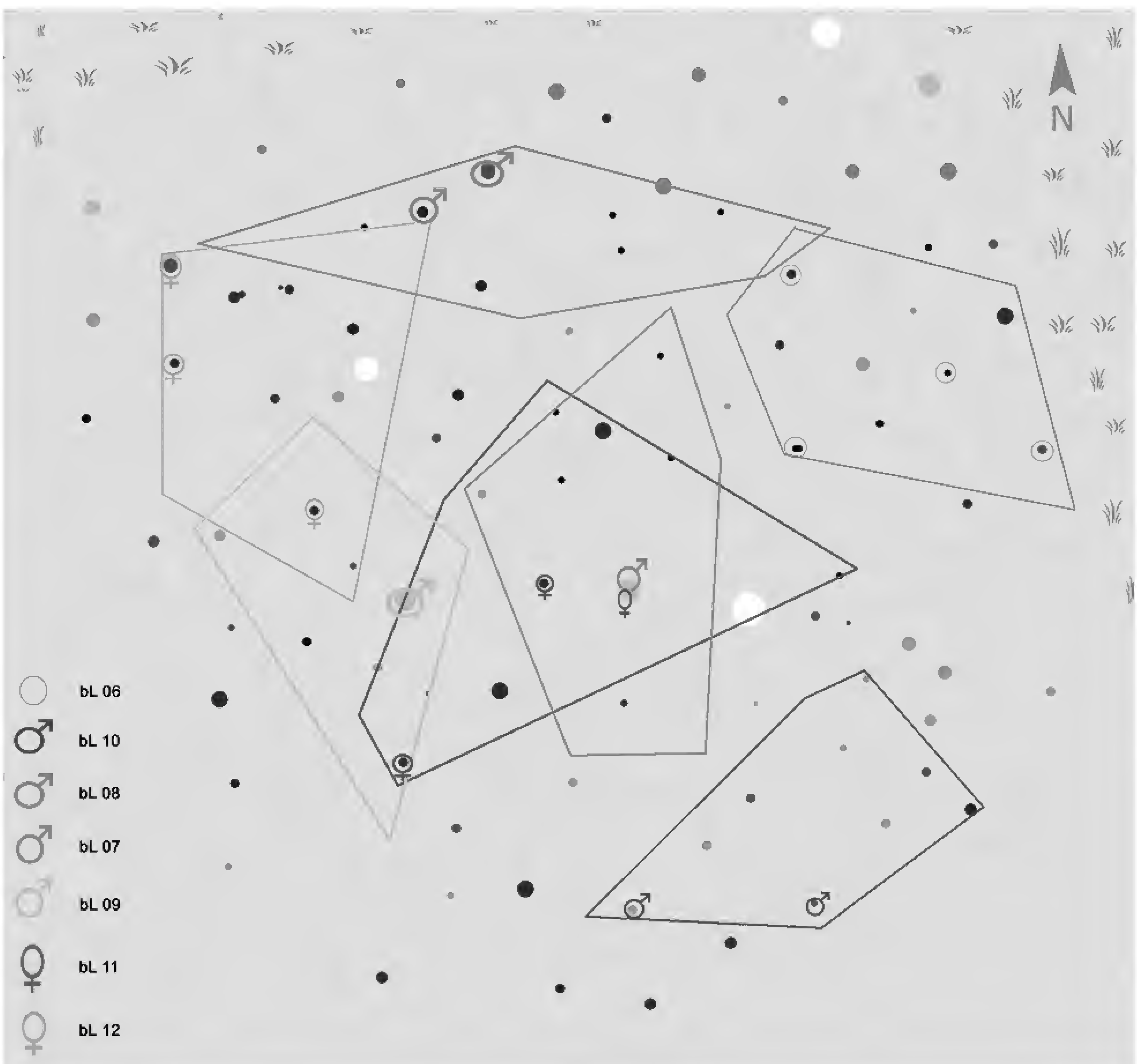

Figure 11. Map of individual territories of lizards in site B.

the day gradually decreased in frequency as time passed. Evidently 90% of *Feeding* was done in the midday hours (1100-1230 hr). During the evening hours from 1400 to 1800 hr, *Still* was demonstrated by 70% of the individuals observed, and all the other behaviors became rarer, especially *Walking* and *Feeding*.

Overall, the behaviors exhibited by the lizards varied with time from morning to evening. Additionally, all individuals at a particular site would synchronize their behavior. For example, when a certain individual would begin the *Gular Sac Display*, all individuals at that particular site would soon perform the *Gular Sac Display* as well. Normally the dominant male would initiate the display with other individuals following with the same A paired *t*-test showed that there is a significant difference in the patterns of behaviors between males and females ($t = 3.10$, $p = 0.004$). Not only were the behaviors shown by males and females markedly different, the percentages of time spent in each behavior differed as well (Fig. 9). *Body-lift* and *Gular Sac Display* were confined to males and *Head-bob* and *Tail-wag* were shared by both sexes, but males had a comparatively higher percentage. About 60% of the observed instances of *Adjustment*, *Still*, and *Walking* were performed by females.

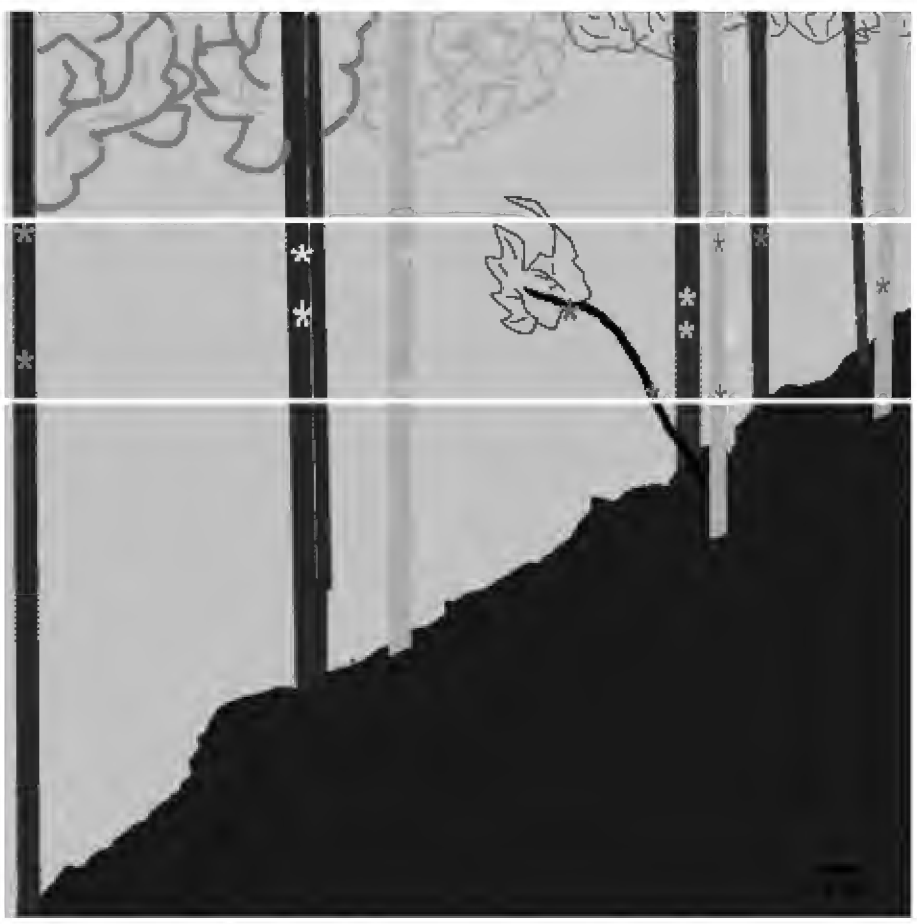

Figure 12. Arboreal distributions of lizards in site A.

One instance of mating behavior of *L. scutatus* was observed in this study. The single observation was about 2.4 m above the ground at 0720 hrs in the morning on a *Syzygium aromaticum* tree with a girth of 42 cm. Copulation was maintained for three minutes, after which both individuals were observed in the same tree for the duration of the day.

Territoriality

The size of territory differed among reproductive groups with females having the largest (264.94 ± 59.8 m^2), followed by males (178.72 ± 32.1 m^2), and then subadults (174.73 ± 32.3 m^2), although males and subadults had roughly equal sized territories (Figs. 10 and 11). A Paired *t*-test showed a significant difference between male and female territories ($t = 2.38$, $p = 0.02$). Territory size was not linked to the body size of the owner ($t = 2.8$, $p = 0.008$).

On five occasions male territories were overlapped by approximately 40% by a female territory and on four

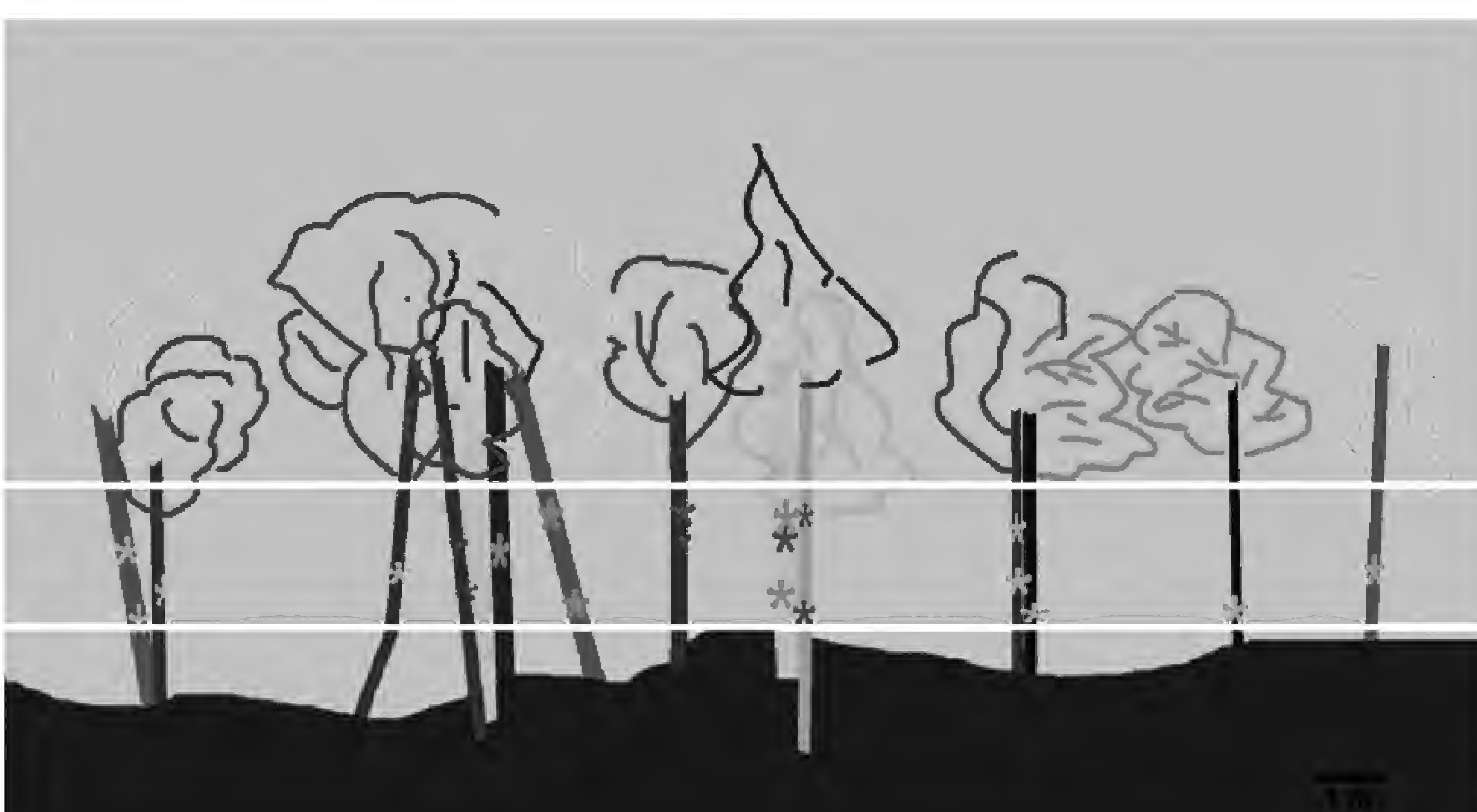

Figure 13. Arboreal distributions of lizards in site B.

occasions male territories were overlapped by approximately 20% by a subadult territory (Table 2). Only on one occasion did a male territory overlap another male territory, although this overlap involved less than 1.0% of each territory. On six occasions female territories were overlapped by approximately 48% by a male territory, and on a single occasion a female territory was overlapped by approximately 11% by the territory of a subadult. On three occasions, subadult territories were overlapped by approximately 15% by a male territory and on a single occasion a subadult territory was overlapped by approximately 18% by the territory of a female. Overlap of territories among the same reproductive group was not observed in this study except on the single occasion of the two males with territories overlapping less than 1.0%. In fact, all males observed in the two study sites were on a tree with no other lizards present (marked with male symbol in Figs. 10 and 11), and they remained on "their" tree throughout the study period with the single exception of the lizard "bL 08" which was recorded occupying two different trees. Males displayed only when they were on their particular tree. Females and subadults were recorded on several trees within their particular home range.

Arboreal distribution

As a group, the lizards of this study showed a previously unreported behavior of maintaining a particular level of height on the trees, especially while displaying. When the observed lizards climbed-up trees they all appear to stop at a similar and consistent elevation. In Site B all the individuals maintained an arboreal height of 2.5 m to 4.1 m, and since the area is rather flat their distribution approximately paralleled the ground. It was only at these positions in the trees that the lizards performed synchronized display behaviors (Figs. 12 and 13). In Site A, which has a slope of 30º, the level of the height of lizards forms about a 60º angle to the ground. Interestingly, at Site A, when the dominant male started to adjust its position all other lizards at the site adjusted their positions, thus maintaining the same height. Individuals in Site B imitated the same pattern of horizontal arboreal plane display among the group.

Discussion

The marking technique we employed proved successful. The use of bands to mark lizards permitted identification of individuals from several meters away and throughout the entire study period because the bands remained in place the entire time. The bands did not reflect sunlight and did not dislodge with shedding of the skin. Furthermore, the presence of the bands did not appear to increase predation vulnerability since the bands were thin and somewhat covered by the hind limbs. This method can be used as a temporary, noninvasive marking technique for other behavioral studies of lizards, instead of the traditionally-used toe clipping, which injures lizards and can alter their behavior.

Figure 14. *Ceratophora tennentii* in Tangappuwa, Dumbara (Knuckles World heritage), Sri Lanka.

Lyriocephalus scutatus showed clear territorial maintenance and site fidelity behaviors at the two study sites at Gannoruwa Forest Reserve. The territorial behavior of *L. scutatus* is a daily-synchronized behavior, initiating with a morning display session followed by ground *Walking*, and in the evening another display session. Behaviors included in territorial maintenance and site fidelity include *Body-lift*, *Gular Sac Display*, *Head-bob*, and *Tail-wag*.

Observations and time budget analysis of the behaviors of the studied lizards show that *Body-lift*, *Head-bob*, *Gular Sac Display* (shown only by males), and *Tail-wag* are important for site fidelity behavior. When lizards display there is a regular order of behaviors (Jennings and Thompson 1999) that begin with *Body-lift* followed by *Head-bob*. While doing *Head-bob* the *Gular Sac Display* is also performed. *Tail-wag* is rare, but when performed it is normally after these previously mentioned behaviors. While lizards are displaying they always hold their *Body-lift* for a long time and while performing other behaviors simultaneously. Observed male lizards held their *Body-lift* from five to 30 minutes, and it is suspected that this might help them appear larger and help in mate attraction. *Gular Sac Display* is only exhibited by males and may be important in sexual selection (Stuart-Fox and

Ord 2004). Body adjustments help lizards to locate one another. The upright position of display in *L. scutatus*, combined with their laterally placed movable eyes on the top of their head, enables them to see others in the group in such a way that lizards are able to distinguish other individuals by their side view.

Many anurans exhibit synchronized calls known as "chorus" behavior (Narins 1992). Likewise, *Lyriocephalus scutatus* shows synchronized territorial maintenance behaviors within a particular group (i.e., individuals within the group display their territorial behaviors simultaneously). When one particular individual starts to display, the other individuals in the same group eventually start their display as well. Synchronized territorial maintenance behavior is important for the recognition of the territory of a particular individual relative to all other individuals in the group from one point of view.

In general, among agamid lizards of Sri Lanka males are known to be territorial (Deraniyagala 1931, 1953; Manamendra-Arachchi 1998; de Silva et al. 2005) and they show territorial behaviors more than females and juveniles. Therefore, it is not entirely surprising that males of *L. scutatus* show *Body-lift*, *Gular Sac Display*, *Head-bob*, and *Tail-wag* whereas females do not. *Adjustment* and *Still* are not territorial maintenance behaviors because all three reproductive groups show them in nearly equal frequencies, with males showing a slightly lower frequency than the others.

Subadults showed the highest frequency of *Walking* among the observed behaviors. This may be due to the process of acquiring a permanent territory. Males were generally more active than females. This disparity between the sexes suggests that *Body-lift*, *Gular Sac Display*, *Head-bob*, and *Tail-wag* are vital territorial maintenance behaviors since they occur most frequently in males.

The three genera *Lyriocephalus*, *Ceratophora*, and *Gonocephalus* are consistently placed within the same clade of the acrodont lizard phylogeny (Macey et al. 2000). *Ceratophora* (Sri Lankan horned lizards) and *Lyriocephalus* are sister taxa (Schulte et al. 2002), while *Gonocephalus*, is the closest Southeast Asian relative of *Lyriocephalus* (Macey et al. 2000). The territorial behavior of the endemic Leaf-nosed horned lizard (*Ceratophora tennentii*) is somewhat similar to *L. scutatus* as observed in previous fieldwork (Fig. 14). They perform *Body-lift* and *Head-bob* but there is a clear difference in the way they hold the body in *Body-lift*; *Ceratophora tennentii* holds its body with a curvature of the spinal column while positioning the legs in similar manner to that of *L. scutatus*. Observations on *Gonocephalus* sp. (Fig. 15) in Lambir Hills National Park, Sarawak, Malaysia show a similar territorial behavior to that of *L. scutatus*, with *Body-lift* and *Gular Sac Display* being performed in a similar manner.

The results presented here show a large difference in the size of male and female territories. Females have

Figure 15. *Gonocephalus* sp. in Lambir Hills National Park, Sarawak, Malaysia.

larger home ranges compared to that of males, which may be due to highly territorial nature of males, and females mainly moving about for feeding and mating. The female territories always overlapped with that of males, which suggests that a single male has access to one or two females. Subadults, on the other hand, have territories that overlap with females and adult males. This may be due to them not being of breeding size and thus not a threat to the resident adult males.

Territory size was not linked to the body size of the owner. The size of the territory might depend on the slope and other physical factors of the land, vegetation cover of the study area, structure of the forest, or human interference in the area. Males had their own defended tree and they do morning and evening displays while perched on that tree. On one occasion a female was found on one of the trees occupied by a male.

This study shows that adult males of *L. scutatus* are highly territorial. Individual males maintain their territories, although their territories can overlap with females and male subadults. Adults of arboreal *Anolis* spp. usually occupy vertical territories such as trees and walls. Since a lizard defends all of the area in which it is found, except perhaps resting and egg laying sites, territory is almost equivalent with home range (Philibosian 1975; Jennings and Thompson 1999). Generally, a lizard spends the entire daylight period moving from one frequented perch site to another, often spending several minutes at a single site. A typical perch position is with the body vertical and head pointing toward the ground at

various angles. The primary activities within the territory include feeding, copulation, and defense, the latter usually against members of the same species and sex, and of similar size. Adults tend to stay in one territory until death, while younger animals are more mobile. Juveniles are usually spatially separated from adults, perching on small rocks and low vegetation. Subadults are often tolerated within adult territories and territories of males and females may overlap (Jennings and Thompson 1999).

Conclusion

The arboreal distribution of the individuals of *L. scutatus* in the same group is a significant behavior and may be novel. This behavior seems to permit the individuals within a group to spot all or most of the other individuals at once, thus increasing the communication among individuals within the group. Further study should be performed to investigate this peculiar behavior of *L. scutatus* more thoroughly. Within the short period of time allowed for the present study, the arboreal distribution of individuals in same group is the foremost finding and it gives us evidence of the hidden eccentric behaviors that agamid lizards possess. Moreover, it may be that other territorial agamid lizards show a similar aerial horizontal distribution and synchronizing display as well. What is clear is that future studies on the behavior of agamid lizards of Sri Lanka are needed since much of their ecology remains unknown.

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Habitat preferences of the endemic shrub frog *Pseudophilautus regius* (Manamendra-Arachchi and Pethiyagoda 2005) at Mihintale Sanctuary, Sri Lanka

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***Abstract.*—Mihintalae is situated in the dry zone of the North Central Province of Sri Lanka, at an elevation of 108 m, and is an under studied site of the habitat of the endemic shrub frog *Pseudophilautus regius*. Six different habitat types which included forest edge, seasonal pond, rock, shrub, grassland, and home garden habitats were selected and systematically sampled to identify the habitat preference of *P. regius*. During the survey, a total of 143 *P. regius* individuals were counted. The highest percentage (53%) of individuals were recorded from the forest edge habitats, 23% from shrub land habitats, 20% from home gardens, and 2% from grassland and seasonal ponds. No individuals were found in the rocky areas. The number of observed individuals of *Pseudophilautus regius* increased with the rainfall in forest habitats and simultaneously decreased in the home gardens. During the dry season the overall turnout of the number of individuals increased in home gardens. However, more extensive and systematic studies, over a longer period of time, are required to estimate the population size and document the fluctuation of *P. regius* and implement suitable conservation measures, if necessary.**

Key words. *Pseudophilautus regius*, habitat preference, Sri Lanka, Mihintale Sanctuary

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Introduction

Sri Lanka is part of the Sri Lanka-Western Ghats biodiversity hotspot with a rich herpetofaunal assemblage (Meegaskumbura et al. 2002; Bossuyt et al. 2004; Meegaskumbura et al. 2009; De Silva 2009; Meegaskumbura and Manamendra-Arachchi 2011). A total of 112 amphibian species are known from Sri Lanka (De Silva et al 2005; Manamendra-Arachchi and Pethiyagoda 2005 and 2006; Meegaskumbura and Manamendra-Arachchi 2005; Meegaskumbura et al. 2010; Meegaskumbura and Manamendra-Arachchi 2011). Among the Sri Lankan amphibians, the most speciose family is the frog family Rhacophoridae. The Rhacophoridae consists of approximately 321 species within two subfamilies and distributed across a wide range of habitats in tropical Africa and south Asia, including India and Sri Lanka (Frost 2008; Li et al. 2008; Yu et al. 2008; Frost 2011). All the Sri Lankan rhacophorids belong to the subfamily Rhacophorinae that contains three genera *Pseudophilautus*, *Polypedates*, and *Taruga* (Manamendra-Arachchi and Pethiyagoda 2005; Meegaskumburaet al. 2010; AmphibiaWeb 2011; Meegaskumbura and Manamendra-Arachchi 2011), of which *Pseudophilautus* is the most diverse with 68 species (Manamendra-Arachchi and Pethiyagoda 2005; Meegaskumbura and Manamendra-Arachchi 2005; Meegaskumbura et al. 2009; Meegaskumbura and Manamendra-Arachchi 2011).

Amphibian diversity of Sri Lanka is directly influenced by climate, vegetation, topography, and geology, and its high rainfall and humidity provide ideal conditions for amphibians. The species richness of *Pseudophilautus* is greatest in the wet zone of Sri Lanka (Manamendra-Arachchi and Pethiyagoda 2005). The only two species of *Pseudophilautus* that have been reported hitherto from the dry zone of Sri Lanka are *P. fergusonianus* (Ahl 1927) and *P. regius* (Manamendra-Arachchi and Pethiyagoda 2005). *Pseudophilautus regius* is an endemic species listed as Data Deficient in the *2007 Red List of Threatened Fauna and Flora of Sri Lanka*. This species is distributed in localized patches of the dry zone (De Silva et al. 2004; Manamendra-Arachchi and Pethiyagoda 2005; Karunarathna and Amarasinghe 2007; Karunarathna et al. 2008; De Silva 2009) including the Mihinthale Sanctuary in the Anuradhapura District (Dissanayake et al. 2011).

Pseudophilautus regius becomes active during the northeast monsoon and inter-monsoonal period (Bahir et

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al. 2005). However, very little is known about its breeding biology (Dubois 2004; Bahiret al. 2005), with the only report being that after amplexus, the female digs a small hole where she lays her eggs and then covers them with soil (Karunarathne and Amarasinghe 2007). Virtually nothing is known about the population size, behavior, dispersal of non-breeding individuals, and habitat preferences of *P. regius*. This study was carried out to unravel the habitat preference of *P. regius* in the Mihintale Sanctuary.

Methods and materials

Study area

Mihintale Sanctuary is located near the town of Mihintale (Anuradhapura District, North Central Province) in the dry zone of Sri Lanka. Annual rainfall in the area of Mihinthale is approximately 1,000-1,500 mm, with most of it occurring during the inter-monsoonal (October and November) and the north-east monsoonal (December until February) periods. The mean annual air temperature is 26 °C with a minimum of 19.5 °C and a maximum of 35 °C. The Mihintale Sanctuary is approximately 2,470 acres (999.6 ha) in extent with no proper demarcated boundaries (Fig. 1).

Methods

The study was carried out from October 2010 to March 2011, with the exception of February 2011. Quadrat sampling (Heinen 1992) in randomly selected points was performed within the Mihintale Sanctuary. A total of twenty-four 10 × 10 m quadrats were sampled at selected points in each habitat type. The habitat types sampled were: Forest Edge (FEH; Fig. 3), Seasonal Pond (SPH; Fig. 4), Rocky Area (RAH; Fig. 9), Shrub Area (SAH), Grassland (GLH; Fig. 5), and Home Garden (HGH). Each habitat consisted of four fixed-quadrat sampling points. Field surveys were conducted from 1800 to 2200 hrs and each sampling site was visited twice a week. A minimum of four people were engaged in the sampling which involved sorting through all leaf litter and searching the branches, tree trunks, and logs within plots. Specimens were identified, photographed, and released at the site of capture. A structured data sheet was used to record data, including environment parameters such as air temperature and relative humidity (RH), which were recorded using a thermometer (-20-100 °C, ± 0.5 °C) and hygrometer (± 4% RH at + 77 °F within 10 to 90% RH ± 5% RH at all other range) respectively.

Results and discussion

A total of 143 individuals of *P. regius* (Fig. 2) were observed from six habitat types during the survey. The highest number was recorded from dry FEH (53%) (Fig. 3), followed by SAH (23%), HGH (20%), GLH (Fig. 5), and SPH (2%) (Fig. 4). No individuals were recorded from RAH during the survey period.

These results suggest that the most preferred habitats of *P. regius* are FEH, SAH, and HGH. Seasonal ponds provide good breeding sites for anurans (Conant and Collins 1991; Gibbs 2000), and according to Dissanayake et al. (2011) SPH had the highest percentage of amphibians recorded in the Mihinthale Sanctuary. However, we recorded few individuals in SPH. This could be because the habitat was surrounded by rocks with no moisture, no thick leaf litter layer (20 mm), or any significant canopy layer (over 70%). GLH was not covered with leaf litter and the area had a higher percentage of *Imperata cylindrica* and *Panicum maximum* grasses, which might be a reason for the low number of individuals recorded in this habitat type, yet more than SPH.

Most anurans are active during a confined period of time in the day or season (Peterson and Dorcas 1992). In many species, vocal advertisement represents the most energetically demanding behavior of males during the adult phase of the life cycle (Ryan 1983; Pough et al. 1992). Furthermore, the calls increase the probability of being exposed to predators. During the survey, most recordings of *P. regius* calling came from FEH and SAH. *Stachytarpheta indica*, *Ageratum conyzoide*, *Clidemia hirta*, *Pterospermum suberifolium*, *Lantana camara*, *Zizyphus oenopila*, *Leucaena leucocephala*, *Acacia leucophloea*, *Drypetes sepiaria, Bauhinia racemosa*, and *Bridelia retusa* were the abundant plant species in these two habitats. Average DBH in FEH was 16.26 cm, including trees with a DBH ≥ 120 cm like *Diospyrose ebenum* that, with small trees, provide a significant canopy layer (over 70%) and a thick leaf litter layer (20 mm). Therefore, FEH and SAH may provide the most preferred habitats for *P. regius*. The canopy cover (>70%) and a moist thick leaf litter layer (20 mm) are important to avoid desiccation and also to lay their direct developing eggs (Bahir et al. 2005; Karunarathne and Amarasinghe 2007). According to Menin et al. (2007) the contradictory relationship of anuran communities and the leaf litter layer can be related to different methods of quantifying litter characteristics such as volume, depth, and dry mass. On the other hand, relationships were found between the depth of leaf litter in many studies on anurans in forests of Costa Rica (Lieberman 1986), Central Amazonia (Tocher et al. 1997), Uganda (Vonesh 2001), and the Southeast region of Brazil (Van Sluys et al. 2007).

In the present study, analysis of rainfall patterns of the sampling locations revealed an increase in the number of observed individuals of *P. regius* immediately after rain in FEH and SAH. This study is in agreement with previous studies that seasonal variation of anuran populations is influenced by rainfall pattern (Das 1996; Weerawardhena et al. 2004). Our data indicates that during the rainy period (monsoon and inter-monsoonal), the number of

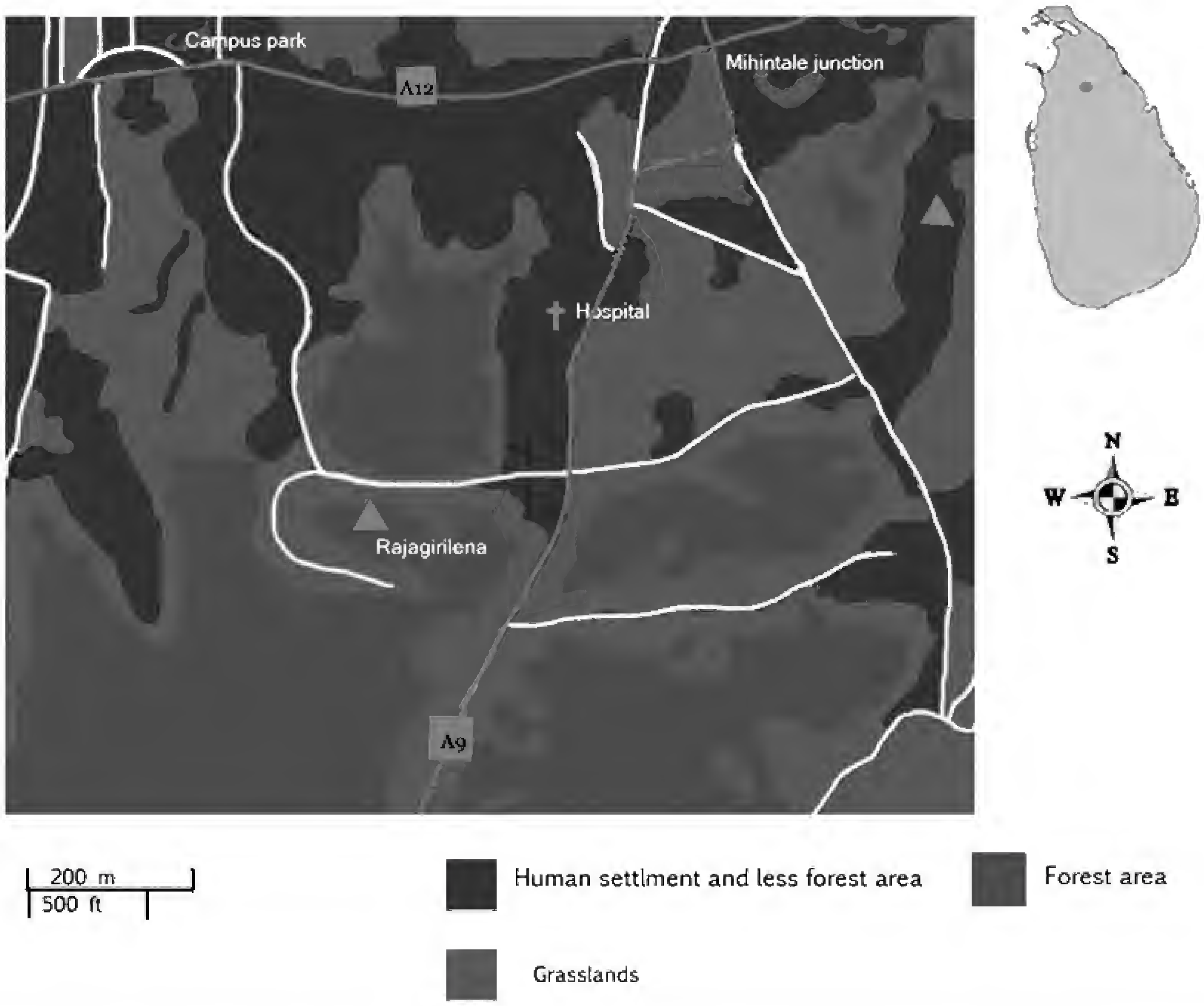

Figure 1. Map of study area.

Figure 2. *Pseudophilautus regius* (mature male).

Figure 3. View of Forest Edge Habitat (FEH).

Figure 4. View of Seasonal Pond Habitat (SPH).

Figure 5. View of Grassland Habitat (GLH).

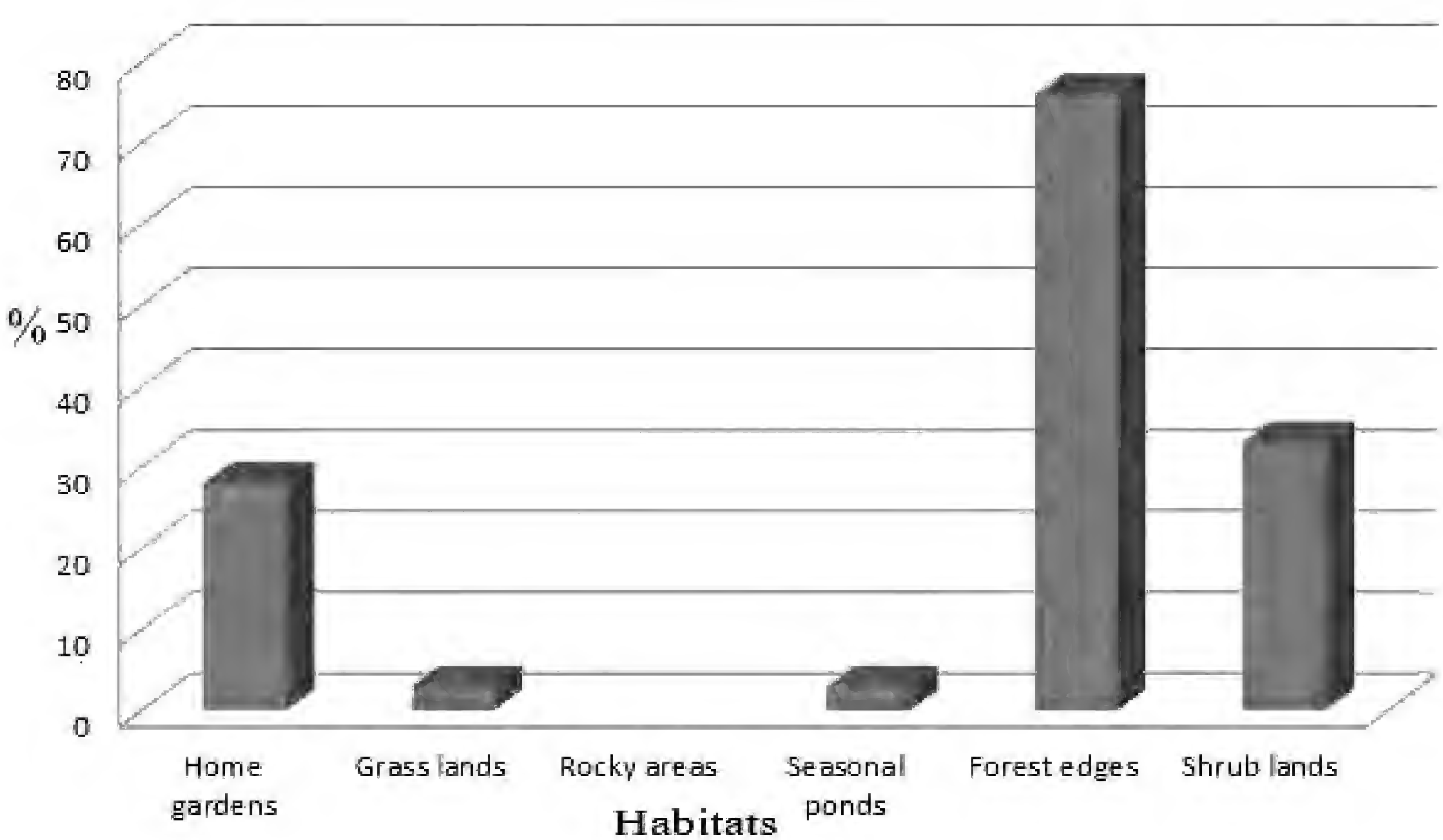

Figure 6. Comparison of the percentage of *Pseudophilautus regius* found in each habitat type.

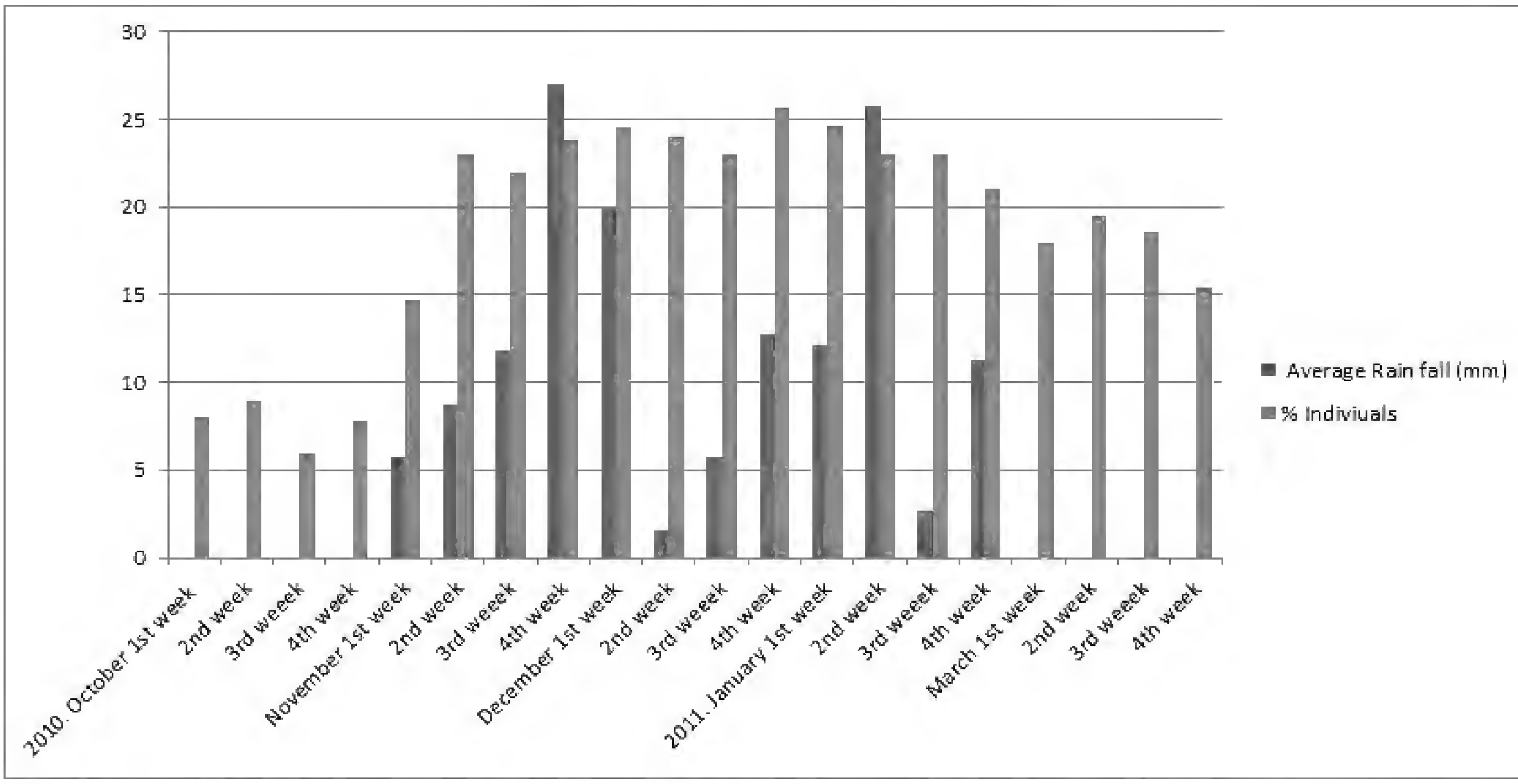

Figure 7. Average rainfall (mm) from October 2010 to March 2011 at the Mihintale Sanctuary, indicating Forest Edge Habitat (FEH).

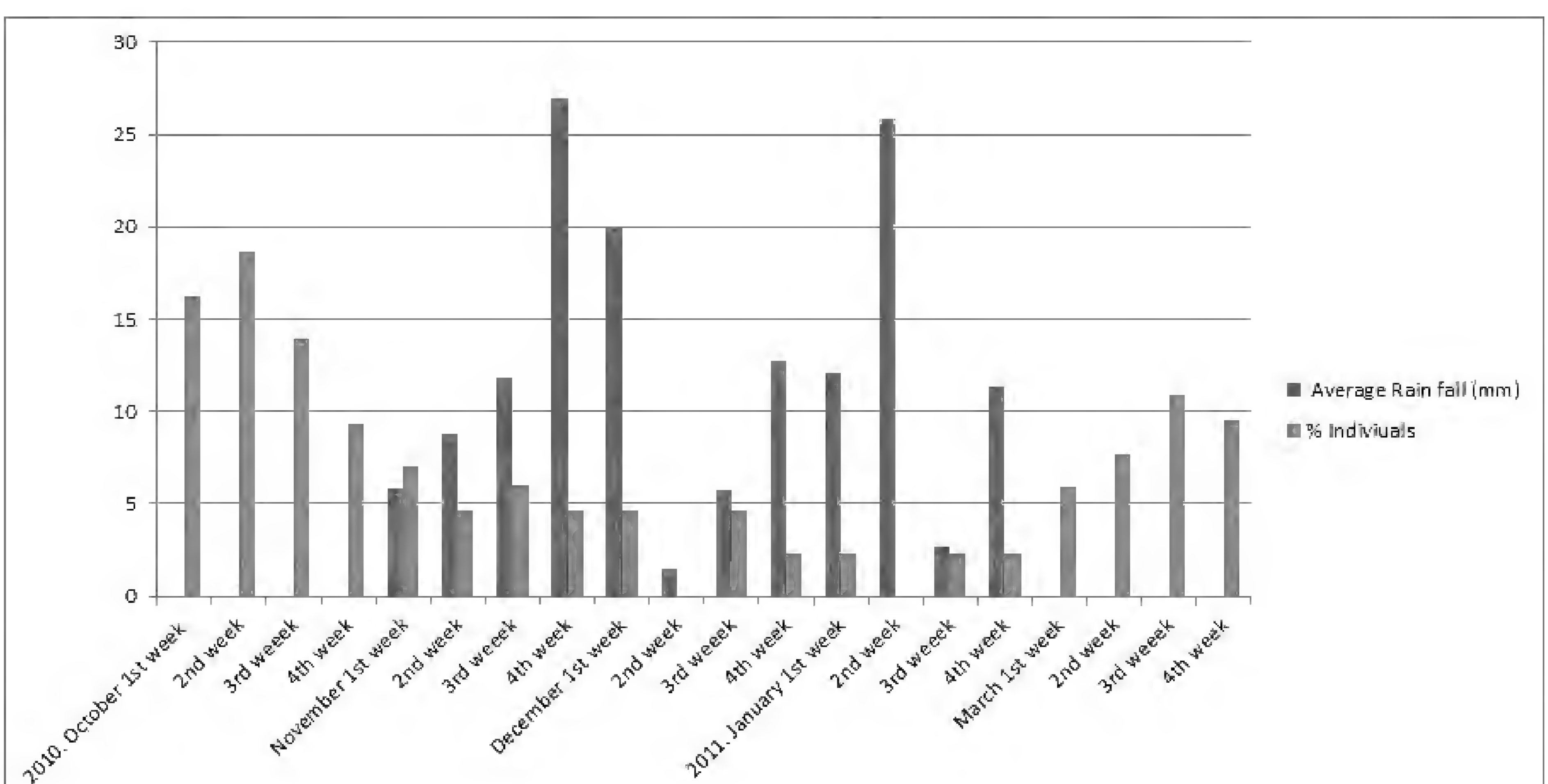

Figure 8. Average rainfall (mm) from October 2010 to March 2011 at the Mihintale Sanctuary, indicating Home Garden Habitat (HGH).

Figure 9. View of Rocky Area Habitat (RAH).

Figure 10. Inside forest: Dry mixed evergreen vegetation with good leaf litter.

individuals of *P. regius* increase in FEH (Fig. 7). However, our study was not conducted in February, although it rained in that month. This study is also in agreement with a study conducted in Madagascar where all amphibian species were edge-avoiders in the dry season but showed different patterns during the wet season (Lehtinen et al. 2003).

In the dry months (October and March) however, the percentage of the number of individuals of *P. regius* were higher in HGH than in the rainy season (November-January) (Fig. 8). This could be because HGH provide various human modified microhabitats that attract frog species like *P. regius*. A high number of individuals were observed near garden water taps and also near bathrooms. This may be because during the dry season forest litter and soil dry-up, although some moisture remains around water taps due to dispersal of water during usage or due to leakages. However, this observation does not indicate that *P. regius* is solely found in disturbed habitats, and could be because this study was conducted for a short time period. Further research conducted at least for a year could reveal possible relationships with relative humidity

Conclusions and recommendations

The habitat type most preferred by *P. regius* is Forest Edge Habitat (53%), whereas Rocky Area Habitat was not. The present study also demonstrates that Home Garden Habitat might provide suitable habitats during the dry season. Additional studies are needed using different sampling methods coupled with behavioral studies to determine the distribution of *P. regius* across the forest habitat and through home garden during the dry season. It was observed that villagers used Mihintale Sanctuary for daily activities including the forest edge for collecting firewood. Furthermore, some residents on the sanctuary boundary disturb the shrubs. These activities can have an adverse effect on the population of *P. regius*. We also saw garbage accumulation in the sanctuary (Fig. 11), which may affect the breeding grounds as it pollutes the forest floor. We strongly suggest that management authorities take necessary steps to minimize and mitigate these adverse impacts in order to conserve the habitat of this endemic shrub frog. Long-term monitoring programs should be conducted to estimate the population fluctuation and implement suitable conservation measures if necessary.

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Figure 11. Garbage accumulation in Mihintale Sanctuary.

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Figure 12. View of forest in Mihintale Sanctuary.

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